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Environmental Pollution Control Alternatives
Drinking Water Treatment for Small Communities

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Technology Transfer

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Environmental Pollution Control Alternatives:

Drinking Water Treatment for Small Communities

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Introduction

Small drinking water systems face a difficult challenge: to provide a safe, sufficient supply of water at a reasonable cost. Our growing awareness of the biological and chemical contaminants that can affect the safety of drinking water has led to the need for more frequent monitoring and reporting and, in some cases, additional or upgraded treatment by water suppliers.

This document provides information for small system owners, operators, managers, and local decision makers, such as town officials, regarding drinking water treatment requirements and the treatment technologies suitable for small systems. It is not intended to be a comprehensive manual for water treatment and protection of public water supplies from sources of contamination. Rather, it is designed to give an overview of the problems a small system may face, treatment options that are available to solve specific problems, and resources that can provide further information and assistance.

Chapter 1 discusses why we need drinking water treatment and gives an overview of drinking water treatment processes.

Chapter 2 provides a summary of existing and new federal drinking water regulations and explains how these regulations affect small systems.

Chapter 3 provides an overview of how to select drinking water treatment technologies and discusses special management issues for small systems.

Chapters 4 through 7 describe technologies that can enable small systems to meet federal drinking water regulations covering filtration, disinfection, removal of organic and inorganic contaminants, and corrosion control. These chapters describe *established* technologies, which are commonly used in the water treatment industry. They also describe several *emerging* technologies suitable for small systems. These technologies have not been widely used, but have proven effective on the pilot scale and are emerging as viable full-scale options for treating water supplies.

Chapter 8 lists organizations, publications, and other resources that can assist small systems in their efforts to provide safe drinking water to consumers.

For the purpose of this document, small systems are defined as systems that serve 25 to 1,000 people, or that have a flow of 9,500 to 380,000 liters (2,500 to 100,000 gallons) per day. They include small community systems as well as noncommunity systems, such as campgrounds and restaurants.

Drinking Water Treatment: An Overview

Why Do We Need Drinking Water Treatment?

For thousands of years, people have treated water intended for drinking to remove particles of solid matter, reduce health risks, and improve aesthetic qualities such as appearance, odor, color, and taste. As early as 2000 B.C., medical lore of India advised, "Impure water should be purified by being boiled over a fire, or being heated in the sun, or by dipping a heated iron into it, or it may be purified by filtration through sand and coarse gravel and then allowed to cool."

Ancient medical lore of India advised that impure water should be purified by heating or filtering through sand and coarse gravel.

Early in the nineteenth century, scientists began to recognize that specific diseases could be transmitted by water. Since that discovery, treatment to eliminate disease-causing microorganisms has dramatically reduced the incidence of waterborne diseases (diseases transmitted through water) such as typhoid, cholera, and hepatitis in the United States. For example, in 1900, 36 out of every 100,000 people died each year from typhoid fever; today there are almost no cases of waterborne typhoid fever in the United States.

Although water treatment processes have greatly improved the quality and safety of drinking water in the United States, there are still over 89,000 cases each year of waterborne diseases caused by microorganisms—bacteria, viruses, protozoa, helminths, and fungi (Figure 1-1).[1] Water can become contaminated with these organisms through surface runoff (water

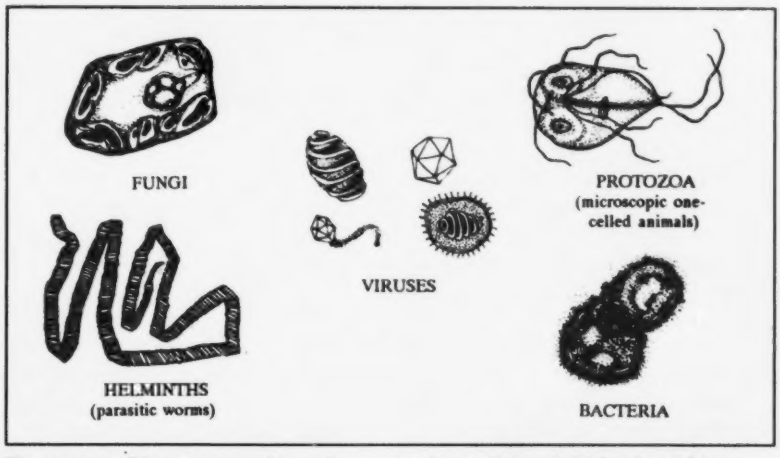

Figure 1-1. Disease-causing microorganisms that might be found in water supplies.

[1]Source: EPA estimate. *Federal Register*, June 19, 1989 (54 FR 27522).

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that travels over the ground during storms), which often contains animal wastes; failures in septic or sewer systems; and sewage treatment plant effluents (outflow). Microbiological contamination occurs most often in surface water, but it can also occur in ground water, usually due to improperly placed or sealed wells. Contamination can also occur after water leaves the treatment plant, through cross connection (connection between safe drinking water and a source of contamination), backflow in a water supply line, or regrowth of microorganisms in the distribution system.

Table 1-1 lists some of the diseases caused by microorganisms found in water supplies. The protozoan *Giardia lamblia* is now the most commonly identified organism associated with waterborne disease in this country. This organism causes giardiasis, which usually involves diarrhea, nausea, and dehydration that can be severe and can in some cases last for months. Over 20,000 water-related cases of this disease have been reported in the last 20 years,[2] with probably many more cases going unreported. Another protozoan disease, cryptosporidiosis, is caused by *Cryptosporidium*, a cyst-forming organism similar to *Giardia*. Other common waterborne diseases include viral hepatitis, gastroenteritis, and legionellosis (Legionnaires' Disease).

Table 1-1. Waterborne Diseases

Waterborne Disease	Causative Organism	Source of Organism in Water	Symptom
Gastroenteritis	Rotavirus	Human feces	Acute diarrhea or vomiting
	Salmonella (bacterium)	Animal or human feces	Acute diarrhea and vomiting
	Enteropathogenic *E. Coli*	Human feces	Acute diarrhea or vomiting
Typhoid	*Salmonella typhosa* (bacterium)	Human feces	Inflamed intestine, enlarged spleen, high temperature—sometimes fatal
Dysentery	*Shigella* (bacterium)	Human feces	Diarrhea — rarely fatal
Cholera	*Vibrio comma* (bacterium)	Human feces	Vomiting, severe diarrhea, rapid dehydration, mineral loss—high mortality
Infectious hepatitis	Hepatitis A (virus)	Human feces, shellfish grown in polluted waters	Yellowed skin, enlarged liver, abdominal pain — low mortality, lasts up to 4 months
Amoebic dysentery	*Entamoeba histolytica* (protozoan)	Human feces	Mild diarrhea, chronic dysentery
Giardiasis	*Giardia lamblia* (protozoan)	Animal or human feces	Diarrhea, cramps, nausea, and general weakness—not fatal, lasts 1 week to 30 weeks
Cryptosporidiosis	*Cryptosporidium* (protozoan)	Animal or human feces	Diarrhea, stomach pain—lasts an average of 5 days

Source: Adapted from American Water Works Association, *Introduction to Water Treatment: Principles and Practices of Water Supply Operations*, Denver, CO, 1984.

Chemical contaminants, both natural and synthetic, might also be present in water supplies. Contamination problems in ground water (used by 85 percent of small systems) are frequently chemical in nature. Common sources of chemical contamination include minerals dissolved from the rocks that form the earth's crust; pesticides and herbicides used in agriculture; leaking underground storage tanks; industrial effluents; seepage from septic tanks, sewage treatment plants, and landfills; and any other improper disposal of chemicals in or on the ground. In some systems, the water quality can promote corrosion of materials in the distribution system, possibly introducing lead and other materials into the drinking water. The water treatment process might also introduce trihalomethanes— chemicals formed when chlorine reacts with natural organic materials and other chemical contaminants—into the drinking water. (It should be noted, however, that while the potential for chlorination by-product formation cannot be

[2] Source: Dave Ryan, "Water Treatment to Combat Illness," *EPA Journal*, December 1987.

neglected, adequate disinfection is of paramount importance to protect the public from microbiological contamination of drinking water.)

Drinking water can be treated for reasons other than to reduce health risks from microorganisms and chemicals. A system might treat water to improve its color, odor, or taste even if it is safe to drink. For example, some systems remove iron and manganese, which can stain laundry and plumbing fixtures. Some communities add fluoride to drinking water to improve dental health.

To protect the public from the health risks of drinking water contaminants, the U.S. Environmental Protection Agency (EPA) has issued regulations covering the quality and treatment of drinking water. These regulations are discussed in Chapter 2.

EPA has also issued guidance for protecting public drinking water from sources of contamination. Protecting ground-water supplies from contaminants reduces the extent of treatment needed to protect public health. The Wellhead Protection (WHP) Program for public water supplies is an example of a protection program. Publications on the WHP Program are listed in Chapter 8, Resources.

How Is Drinking Water Treated?

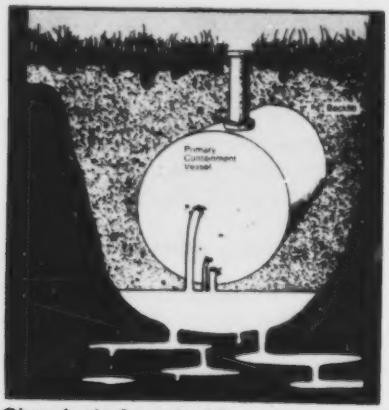
Table 1-2 shows the types and goals of water treatment processes typically used by small systems (including preliminary treatment and main water

Table 1-2. Water Treatment Processes

Process/Step	Purpose
Preliminary Treatment Processes[a]	
Screening	Removes large debris (leaves, sticks, fish) that can foul or damage plant equipment
Chemical pretreatment	Conditions the water for removal of algae and other aquatic nuisances
Presedimentation	Removes gravel, sand, silt, and other gritty material
Microstraining	Removes algae, aquatic plants, and small debris
Main Treatment Processes	
Chemical feed and rapid mix	Adds chemicals (coagulants, pH adjusters, etc.) to water
Coagulation/flocculation	Converts nonsettleable to settleable particles
Sedimentation	Removes settleable particles
Softening	Removes hardness-causing chemicals from water
Filtration	Removes particles of solid matter which can include biological contamination and turbidity
Disinfection	Kills disease-causing microorganisms
Adsorption using granular activated carbon (GAC)	Removes radon and many organic chemicals such as pesticides, solvents, and trihalomethanes.
Aeration	Removes volatile organic chemicals (VOCs), radon, H_2S, and other dissolved gases; oxidizes iron and manganese
Corrosion control	Prevents scaling and corrosion
Reverse osmosis, electrodialysis	Removes nearly all inorganic contaminants
Ion exchange	Removes some inorganic contaminants, including hardness-causing chemicals
Activated alumina	Removes some inorganic contaminants
Oxidation filtration	Removes some inorganic contaminants (e.g., iron, manganese, radium)

[a]Generally used for treating surface water supplies.

Source: Adapted from American Water Works Association, *Introduction to Water Treatment*, Vol. 2, 1984.



Chemicals from leaking underground storage tanks might migrate to ground water and/or surface water.

treatment processes). This document discusses the water treatment processes designed to protect the consumer from waterborne disease. Chapter 3 discusses how to select appropriate processes and technologies for a particular water system, and Chapters 4 through 7 discuss treatment technologies in more detail.

Filtration

Filtration is the process of removing particles of solid matter from water, usually by passing the water through sand or other porous materials. Filtration helps to control biological contamination and turbidity. (Turbidity is a measure of the cloudiness of water caused by the presence of suspended matter. Turbidity can shelter harmful microorganisms and reduce disinfection effectiveness.) Filtration technologies commonly used in small systems include slow sand filtration, diatomaceous earth filtration, and package filtration systems. Filtration is discussed in Chapter 4.

Disinfection

Disinfection is a chemical and/or physical process that kills disease-causing organisms. For the past several decades, chlorine (as a solid, liquid, or gas) has been the disinfectant of choice in the United States because it is effective and inexpensive and can provide a disinfectant residual in the distribution system. However, under certain circumstances, chlorination might produce potentially harmful by-products, such as trihalomethanes. Small systems can successfully use ozone and ultraviolet radiation as primary disinfectants, but chlorine or an appropriate substitute must also be used as a secondary disinfectant to prevent regrowth of microorganisms in the distribution system. Disinfection is discussed in Chapter 5.

Runoff from agricultural areas can introduce microbiological contaminants, pesticides, and nitrates into drinking water sources.

Treatment of Organic Contaminants

Many synthetic organic chemicals (SOCs), manmade compounds that contain carbon, have been detected in water supplies in the United States. Some of these, such as the solvent trichloroethylene, are volatile organic chemicals (VOCs). VOCs easily become gases and can be inhaled in showers or baths or while washing dishes. They can also be absorbed through the skin.

Water supplies become contaminated by organic compounds from sources such as improperly disposed wastes, leaking gasoline storage tanks, pesticide use, and industrial effluents. Technologies that can be used effectively by small systems to remove these contaminants include activated carbon and aeration. These technologies are discussed in Chapter 6.

Treatment of Inorganic Contaminants

The inorganic contaminants in water supplies consist mainly of naturally occurring elements in the ground, such as arsenic, barium, fluoride, sulfate, radon, radium, and selenium. Industrial sources can contribute metallic substances to surface waters. Nitrate, an inorganic substance frequently found in ground-water supplies, is found predominantly in agricultural areas due to the application of fertilizers. High levels of total dissolved solids (TDS) might, in some instances, require removal to produce a potable supply.

Inorganic chemicals might also be present in drinking water due to corrosion. Corrosion is the deterioration

or destruction of components of the water distribution and plumbing systems by chemical or physical action, resulting in the release of metal and nonmetal substances into the water. The metals of greatest health concern are lead and cadmium; zinc, copper, and iron are also by-products of corrosion. Asbestos can be released by corrosion of asbestos-cement pipe. Corrosion reduces the useful life of the water distribution and plumbing systems. It can also promote microorganism growth, resulting in disagreeable tastes, odors, and slimes.

Treatment alternatives for inorganic contaminants include removal techniques and corrosion controls. Removal technologies — coagulation/filtration, reverse osmosis, ion exchange, and activated alumina — treat source water that is contaminated with metals or radioactive substances (such as radium). Aeration effectively strips radon gas from source waters. Corrosion controls reduce the presence of corrosion by-products such as lead at the point of use (such as the consumer's tap). Treatment technologies for inorganic contaminants are discussed in Chapter 7.

New and Proposed Drinking Water Regulations: An Overview

In 1974, Congress passed the Safe Drinking Water Act (SDWA), setting up a regulatory program among local, state, and federal agencies to help ensure the provision of safe drinking water in the United States.

Under the SDWA, the federal government develops national drinking water regulations to protect public health and welfare. The states are expected to administer and enforce these regulations for public water systems (systems that either have 15 or more service connections or regularly serve an average of 25 or more people daily for at least 60 days each year). Public water systems must provide water treatment, ensure proper drinking water quality through monitoring, and provide public notification of contamination problems.

Congress significantly expanded and strengthened the SDWA in 1986. The 1986 amendments include provisions on the following:

- ***Maximum Contaminant Levels.*** The Safe Drinking Water Act required EPA to set numerical standards, referred to as Maximum Contaminant Levels (MCLs), or treatment technique requirements for contaminants in public water supplies. The 1986 amendments established a strict schedule for EPA to set MCLs or treatment requirements for previously unregulated contaminants.
- ***Monitoring.*** EPA must issue regulations requiring monitoring of all regulated and certain unregulated contaminants, depending on the number of people served by the system, the source of the water supply, and the contaminants likely to be found.
- ***Filtration.*** EPA must set criteria under which systems are obligated to filter water from surface water sources. It must also develop procedures for states to determine which systems have to filter.
- ***Disinfection.*** EPA must develop rules requiring all public water supplies to disinfect their water.
- ***Use of lead materials.*** The use of solder or flux containing more than 0.2 percent lead, or pipes and pipe fittings containing more than 8 percent lead, is prohibited in public water supply systems. Public notification is required where there is lead in construction materials of the public water supply system, or where the water is sufficiently corrosive to cause leaching of lead from the distribution system/lines.
- ***Wellhead protection.*** The 1986 SDWA amendments require all states to develop Wellhead Protection Programs. These programs are designed to protect public water supplies from sources of contamination.

The impact of these new regulations on small systems will generally concern some fundamental aspects of water treatment. Many systems will be required to improve treatment for removal of microorganisms (through the addition of filtration and/or disinfection processes). Most small systems do not face contamination by organic and inorganic chemicals at levels exceeding the MCLs, and therefore will not need to install treatment for removal of these chemicals.[3] Small systems will be required to conduct periodic monitoring, however, to document whether chemical contaminants are present in their water supplies. Future regulations covering radioactive substances (particularly radon) and disinfection by-products could also have a significant impact.

[3] G. Wade Miller, John E. Cromwell, III, Frederick A. Marrocco. "The Role of the States in Solving the Small System Dilemma," *JAWWA*, August 1988, pp 31-37.

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The rest of this chapter explains the major provisions of EPA's new and proposed drinking water regulations as they apply to small systems. *In addition to the federal regulations discussed here, the water supplier should check with the state agency responsible for drinking water (see Chapter 8, Resources) to find out about state regulations that apply to drinking water treatment facilities.*

Compliance Schedules

Most of the regulations contain compliance schedules that affect large systems initially and small water systems 2 to 4 years later. This means that small systems have additional time to plan for their specific compliance requirements.

The SDWA recognizes that meeting drinking water standards might place a large burden on small systems. The law therefore provides for variances, allowing small systems to meet a less stringent standard if an organic or inorganic contaminant cannot be removed due to the quality of the raw water or other good reasons, as long as the less stringent standard poses no unreasonable health risk. A small system may also be granted a temporary exemption if economic conditions prevent the system from making necessary corrections, provided no unreasonable risk to public health results. No exemptions are allowed for disinfection of surface supplies or the coliform rule for all public water supplies. Monitoring requirements may also be reduced in some cases if the public water supply has a program under an EPA-approved state Wellhead Protection Program.

Maximum Contaminant Levels

A Maximum Contaminant Level, or MCL, is the highest allowable concentration of a contaminant in drinking water. In developing drinking water regulations, EPA establishes Maximum Contaminant Level Goals (MCLGs), which are the maximum levels of contaminants at which no known or anticipated adverse health effects will occur. MCLs are set as close to the MCLG as is feasible. In setting an MCL, EPA takes into account the technical feasibility of control systems for the contaminant, the analytical detection limits, and the economic impact of regulating the contaminant. An MCL is usually expressed in milligrams per liter (mg/L), which is equivalent to parts per million (ppm) for water quality analysis.

The SDWA amendments direct EPA to establish MCLs for 83 specific contaminants and to develop a list of contaminants every 3 years to be considered for regulation. The Agency must promulgate at least 25 MCLs from each of these lists starting in 1991. EPA may set treatment technology requirements instead of MCLs when it is difficult or expensive for water suppliers to test for specific contaminants.

Whenever EPA establishes an MCL for a particular contaminant, the Agency must also identify the Best Available Technology (BAT)[4] for

Community, Nontransient Noncommunity, and Transient Noncommunity Systems

The drinking water regulations distinguish between community water systems (CWS), nontransient noncommunity water systems (NNWS), and transient noncommunity water systems (TNWS).

- A ***community system*** is a public water system that serves at least 15 service connections used by year-round residents, or regularly serves at least 25 year-round residents. Community systems include mobile home courts and homeowner associations.
- A ***nontransient noncommunity system*** regularly serves at least 25 of the same people over six months of the year. Examples are schools and factories.
- ***Transient noncommunity systems,*** such as restaurants, gas stations, and campgrounds, serve intermittent users.

The regulations governing each of these systems are slightly different. This is because certain contaminants cause health problems only when consumed on a regular basis over a long period of time, and are therefore of greater concern in systems that regularly serve the same people than in those that serve transient users.

Only the MCLs for turbidity, nitrate, and bacteria apply to transient noncommunity systems. (The new surface water treatment requirements, explained below in this chapter, will replace the currently MCL for turbidity for TNWS). Most MCLs are set at levels designed to prevent health effects caused by long-term consumption of drinking water from a system. However, the presence of nitrate, bacteria, and turbidity indicate the potential of the water to cause illness even from short-term consumption, so MCLS for these contaminants apply to transient noncommunity as well as other systems.

[4] EPA determines the BAT based on high removal efficiency of contaminant concentration; general geographic applicability; service life; compatibility with other water treatment processes; and ability to achieve compliance at a reasonable cost.

removing that contaminant. To comply with the MCL, public water systems are required to use the BAT or an alternative treatment technology determined by the state to be at least as effective as the BAT.

MCLs for Volatile Organic Compounds

EPA has issued final MCLs for 8 volatile organic compounds. These are shown in Table 2-1. Nontransient noncommunity water systems as well as community systems must meet these MCLs.

Table 2-1. Volatile Organic Chemicals: Final MCLs (in mg/L)

Chemical	Final MCL
Trichloroethylene	0.005
Carbon tetrachloride	0.005
Vinyl chloride	0.002
1,2-Dichloroethane	0.005
Benzene	0.005
para-Dichlorobenzene	0.075
1,1-Dichloroethylene	0.007
1,1,1-Trichloroethane	0.2

Source: *Federal Register*, July 8, 1987 (52 FR 25690).

MCLs for Inorganic and Synthetic Organic Compounds

The final MCL for fluoride has been set at 4.0 mg/L (see *Federal Register* April 2, 1986 - 41 FR 11396).[5] EPA has proposed MCLs for lead and copper (Table 2-2), and for 8 other inorganic compounds and 30 synthetic organic chemicals (Table 2-3). Table 2-3 shows proposed MCLs along with maximum allowable levels under regulations currently in effect.

MCLs for the inorganic chemicals and synthetic organic chemicals in Table 2-4 will be proposed in the near future.

MCLs for Microbiological Contaminants

EPA has set final MCLs for total coliforms (Table 2-5). Coliforms are usually present in water contaminated with human and animal feces and are often associated with disease outbreaks. Although total coliforms include microorganisms that do not usually cause disease themselves, their presence in drinking water might mean that disease-causing organisms are also present. All public water systems must meet the MCL for total coliforms; monitoring requirements are discussed below.

For surface water (or ground water under the direct influence of surface water)[6] EPA has set treatment requirements instead of MCLs for *Giardia*, viruses, heterotrophic bacteria, *Legionella*, and turbidity. These requirements are explained below under Surface Water Treatment Requirements. EPA intends to issue disinfection regulations for ground water, including regulations to control the level of viruses, *Legionella*, and heterotrophic bacteria, at a later date.

MCLs for Radionuclide Contaminants

New MCLs for radionuclides (radioactive elements) will be proposed in the future. The anticipated MCL for radon, a naturally occurring radionuclide, might affect many small public water supplies. Table 2-6 shows the current MCLs for radiological contaminants. Note that only systems serving populations greater than 100,000 people are required to meet MCLs for manmade radionuclides.

MCLs for Disinfectants and Disinfection By-Products

In 1979, EPA established an MCL for total trihalomethanes—chloroform, bromoform, bromodichloromethane, and dibromochloromethane—of 0.1 milligram per liter. This MCL applies only to systems serving populations

Table 2-2. Lead and Copper: Proposed MCLs

(Measured as water leaves the treatment plant or enters the distribution system)

Lead	0.005 mg/L
Copper	1.3 mg/L

Source: *Federal Register*, August 18, 1988 (53 FR 31571).

[5] See Chapter 8, Resources, for information about the *Federal Register*.

[6] Any water beneath the surface of the ground with (i) significant occurrence of insects or other microorganisms, algae, or large-diameter pathogens such as *Giardia lamblia*, or (ii) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions. Direct influence must be determined for individual sources in accordance with criteria established by the state.

Table 2-3. Proposed MCLs for Synthetic Organic Chemicals and Inorganic Chemicals

Contaminant	Existing NPDWR[a] (mg/L)	Proposed MCL (mg/L)
Acrylamide	—	TT[b]
Alachlor	—	0.002
Aldicarb	—	0.0l
Aldicarb sulfoxide	—	0.01
Aldicarb sulfone	—	0.04
Atrazine	—	0.003
Carbofuran	—	0.04
Chlordane	—	0.002
cis-1,2-Dichloroethylene	—	0.07
Dibromochloropropane (DBCP)	—	0.0002
1,2-Dichloropropane	—	0.005
o-Dichlorobenzene	—	0.6
2,4-D	0.1	0.07
Ethylenedibromide (EDB)	—	0.00005
Epichlorphydrin	—	TT[b]
Ethylbenzene	—	0.7
Heptachlor	—	0.0004
Heptachlor epoxide	—	0.0002
Lindane	0.004	0.0002
Methoxychlor	0.1	0.4
Monochlorobenzene	—	0.1
PCBs (as decachlorobiphenyl)	—	0.005
Pentachlorophenol	—	0.2
Styrene[c]	—	0.005/0.1
Tetrachloroethylene	—	0.005
Toluene	—	2.0
2,4,5-TP (Silvex)	0.01	0.05
Toxaphene	0.005	0.005
trans-1,2-Dichloroethylene	—	0.1
Xylenes (total)		10.0
Asbestos	—	7 F/L[d]
Barium	1.0	5.0
Cadmium	0.010	0.005
Chromium	0.05	0.1
Mercury	0.002	0.002
Nitrate (as nitrogen)	10.0	10.0
Nitrite (as nitrogen)	—	1.0
Selenium	0.01	0.05

[a]NPDWR = National Primary Drinking Water Regulations.
[b]TT = Treatment Technique.
[c]EPA proposes MCLs of 0.1 mg/L based on a group C carcinogen classification and 0.005 mg/L based on a B2 classification.
[d]7 million fibers/liter (only fibers longer than 10 m).

Source: *Federal Register*, May 22, 1989 (54 FR 22064).

greater than 10,000 people. EPA plans to propose new rules for groundwater disinfection and for disinfection by-products; small systems might be included in these new requirements. Disinfectants and disinfection by-products that might be included in these rules are shown in Table 2-7.

Monitoring

New monitoring requirements for chemical contaminants under the 1986 SDWA amendments could have a major impact on small systems. These new requirements are explained below.

Volatile Organic Chemicals

All systems must monitor for the regulated VOCs in Table 2-1 and the unregulated VOCs in Table 2-8. The required monitoring is shown in Table 2-9. Small systems serving fewer than 3,300 people must complete initial monitoring for these VOCs by December 31, 1991. Nontransient noncommunity systems, as well as community systems, must meet the requirements for VOCs.

Fluoride

Monitoring requirements for fluoride are shown in Table 2-10.

Other Inorganic and Synthetic Organic Chemicals

EPA has proposed monitoring requirements for 38 regulated chemicals and 111 unregulated contaminants (inorganic and synthetic organic chemicals). In addition, EPA will propose monitoring requirements for chemicals in Table 2-4.

Radionuclides

Currently, community systems must monitor for natural radiological chemicals every 4 years. EPA will be proposing new monitoring requirements for radionuclides, including radium-226, radium-228, uranium (natural), and radon.

Microbiological Contaminants

- **Total coliforms.** In June 1989, EPA issued new monitoring requirements for total coliforms, effective December 31, 1990. Tables 2-11 and 2-12, respectively, show the minimum number of routine and repeat samples required.
- **Fecal coliforms/*Escherichia coli*.** The presence of fecal coliforms in drinking water is strong evidence of recent sewage contamination, and indicates that an urgent public health problem probably exists. Therefore, EPA requires that public water systems analyze each sample that is positive for total coliforms to determine if it contains fecal coliforms. Alternatively, the system may test for the bacterium *Escherichia coli* instead of fecal coliforms. The requirements for monitoring fecal coliforms and *E. coli* are effective December 31, 1990.
- **Heterotrophic bacteria.** Heterotrophic bacteria can interfere with total coliform analysis. Effective December 31, 1990, public water systems must follow specific procedures to minimize this interference.

Table 2-4. Inorganic and Synthetic Organic Chemicals to be Regulated

Arsenic[a]	Sulfate
Methylene chloride	Hexachlorocyclopentadiene
Antimony	Nickel
Endrin[b]	Thallium
Dalapon	Beryllium
Diquat	Cyanide
Endothall	1,1,2-Trichloroethane
Glyphosate	Vydate
Andipates	Simazine
2,3,7,8-TCDD (Dioxin)	PAHs
Trichlorobenzene	Atrazine

[a]Current MCL is 0.05 mg/L.
[b]Current MCL is 0.0002 mg/L.

Source: U.S. Environmental Protection Agency, Fact Sheet. "Drinking Water Regulations under 1986 Amendments to SDWA," February 1989.

Table 2-5. Maximum Contaminant Level for Total Coliforms

- Compliance is based on presence/absence of total coliforms in sample. rather than on an estimate of coliform density.
- MCL for systems analyzing at least 40 samples/month: no more than 5.0 percent of the monthly samples may be total coliform-positive.
- MCL for systems analyzing fewer than 40 samples/month: no more than 1 sample/month may be total coliform-positive.
- A public water system must demonstrate compliance with the MCL for total coliforms each month it is required to monitor.
- MCL violations must be reported to the state no later than the end of the next business day after the system learns of the violation.

Source: U.S. Environmental Protection Agency, Fact Sheet. "Drinking Water Regulations under 1986 Amendments to SDWA," February 1989.

Table 2-6. Maximum Contaminant Levels for Radiological Chemicals

	Natural Radionuclides		Manmade Radionuclides		
	Gross Alpha	Combined Radium 226 & 228	Gross Beta	Tritium	Strontium 90
Community Systems	15 pCi/L	5 pCi/L	50 pCi/L[b]	20,000 pCi/L[b]	8 pCi/L[b]
Noncommunity Systems	State option	State option	State option	State option	State option

[a]Picocuries per liter (pCi/L) is a measure of the concentration of a radioactive substance. A level of 1 pCi/L means that approximately 2 atoms of the radionuclide per minute are disintegrating in every liter of water.
[b]Applies only to surface water systems serving populations greater than 100,000 people.

Source: Adapted from National Rural Water Association, *Water System Decision Makers: An Introduction to Water System Operation and Maintenance*, Duncan, OK, 1988.

Table 2-7. Disinfectants and Disinfectant By-Products

Disinfectants and Residuals

Chlorine, hypochlorous acid, and hypochlorite ion
Chlorine dioxide, chlorite, and chlorate
Chloramines and ammonia
Ozone

Disinfectant By-Products

Trihalomethanes: chloroform, bromoform, bromodichloromethane, dibromochloromethane
Haloacetonitriles: bromochloroacetonitrile, dibromochloroacetonitrile, dichlorobromoacetonitrile, trichloroacetonitrile
Haloacetic acids: mono-, di-, and tri-chloroacetic acids; mono- and dibromoacetic acids
Haloketones: 1,1-dichloropropanone and 1,1,1-tri-chloropropanone
Other: chloral hydrate, chloropicrin

Cyanogen chloride
Chlorophenols (2-chlorophenol, 2,4-dichlorophenol, 2,4,6-trichlorophenol)
N-organochloramines

MX[3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone)]

Ozone by-products

Source: U.S. Environmental Protection Agency, Fact Sheet. "Drinking Water Regulations under 1986 Amendments to SDWA," February 1989.

Table 2-8. Monitoring for Unregulated VOCs

Required for All Systems:

Chloroform
Bromodichloromethane
Chlorodibromomethane

Bromoform
trans-1,2-Dichloroethylene
Chlorobenzene

m-Dichlorobenzene
Dichloromethane
cis-1,2-Dichloroethylene

o-Dichlorobenzene
Dibromomethane
1,1-Dichloropropane

Tetrachloroethylene
Toluene
p-Xylene

o-Xylene
m-Xylene
1,1-Dichloroethane

1,2-Dichloropropane
1,1,2,2-Tetrachloroethane
Ethylbenzene

1,3-Dichloropropane
Styrene
Chloromethane

Bromomethane
1,2,3-Trichloropropane
1,1,1,2-Tetrachloroethane

Chloroethane
1,1,2-Trichloroethane
2,2-Dichloropropane

o-Chlorotoluene
p-Chlorotoluene
Bromobenzene

1,3-Dichloropropane
Ethylene dibromide
1,2-Dibromo-3-chloropropane

Required for Vulnerable Systems* Only:

1,2-Dibromo-3-chloropropane (DBCP)
Ethylenedibromide (EDB)

At Each State's Discretion:

1,2,4-Trimethylbenzene
1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene

n-Propylbenzene
n-Butylbenzene
Naphthalene

Hexachlorobutadiene
Bromochloromethane

1,3,5-Trimethylbenzene
p-Isopropyltoluene
Isopropylbenzene

tert-Butylbenzene
sec-Butylbenzene
Fluorotrichloromethane

Dichlorodifluoromethane

*A system's vulnerability to contamination is assessed by evaluating factors such as geological conditions, use patterns (e.g., pesticides), type of source, location of waste disposal facilities, historical monitoring record, and nature of the distribution system.

Source: Adapted from U.S. Environmental Protection Agency, Fact Sheet. "Drinking Water Regulations under 1986 Amendments to SDWA," February 1989.

Table 2-9. Compliance Monitoring for Regulated and Unregulated Volatile Organic Chemicals

Initial monitoring: All community and nontransient noncommunity systems must monitor each source at least once within 4 years.

- Surface waters: four quarterly samples.
- Ground water: four quarterly samples; state can exempt systems from subsequent monitoring if no VOCs are detected in the first sample.
- Composite samples of up to five sources are allowed.

Repeat monitoring: varies from quarterly to once every 5 years. The frequency is based on whether VOCs are detected in the first round of monitoring and whether the system is vulnerable to contamination.

Source: Adapted from U.S. Environmental Protection Agency, Fact Sheet. "Drinking Water Regulations under 1986 Amendments to SDWA," February 1989.

- **Sanitary surveys.** Periodic sanitary surveys are required for all systems that collect fewer than five coliform samples per month. (A sanitary survey is a comprehensive review of a system's operations, including watershed control, the disinfection system, raw water quality, and monitoring, to determine whether operational requirements are being met.) The schedule for conducting sanitary surveys is shown in Table 2-13.

Laboratory Analysis and Sampling Requirements

To meet the monitoring requirements for some contaminants, small systems will need the services of a commercial laboratory. For compliance monitoring purposes, analyses must be performed in an EPA or state-approved laboratory. Contact the Safe Drinking Water Hotline (see Chapter 8, Resources) for assistance in locating a certified drinking water laboratory in your area. (These laboratories must successfully analyze performance evaluation samples within limits set by EPA.)

To ensure proper sampling and analysis[7]:

- Samples must be collected in proper containers and preserved as necessary. Discuss sample collection procedures for the contaminant with the laboratory in advance. (See Appendix A for bacteriological sample collection procedures.)
- Sample chain of custody must be maintained (to ensure that someone is always accountable for the sample).
- Analysis must be performed within specified holding times (the period of time between sample collection and analysis).
- Approved analytical procedures must be used.
- Adequate quality assurance data must be generated within the laboratory.

A water system manager should obtain the following information from a laboratory he or she plans to use:

- References of similar work
- Copy of applicable accreditations or certifications
- Information about availability and cost of sample containers, preservatives, and shipping containers
- Commitment or estimate of project turnaround
- Definition of analytical methods, detection limits, and cost of analysis
- Type of quality assurance data that will be reported
- State-approved reporting forms, if applicable
- Fees

Table 2-10. Monitoring Requirements for Fluoride

Surface waters:	1 sample each year
Ground waters:	1 sample every 3 years
Minimum repeat:	1 sample every 10 years

Source: *Federal Register*, April 2, 1986 (41 FR 11396).

[7] From Metcalf and Eddy, *A Guide to Water Supply Management in the 1990s*, Wakefield, MA, November 1989.

Table 2-11. Total Coliform Sampling Requirements According to Population Served

Population Served	Minimum Number of Routine Samples Per Month[a]
25 to 1,000[b]	1
1,001 to 2,500	2
2,501 to 3,300	3

[a]In lieu of the frequency specified in this table, a noncommunity water system using only ground water (except ground water under the direct influence of surface water) and serving 1,000 persons or fewer may monitor at a lesser frequency specified by the state (in writing) until a sanitary survey is conducted and the state reviews the results. Thereafter, such systems must monitor in each calendar quarter during which the system provides water to the public unless the state determines (in writing) that some other frequency is more appropriate. Beginning June 29, 1994, such systems must monitor at least once every year.

A noncommunity water system using surface water, or ground water under direct influence of surface water, regardless of the number of persons served, must monitor at the same frequency as a like-sized community water system, i.e., the frequency specified in the table. A noncommunity water system using ground water (which is not under the direct influence of surface water) and serving more than 1,000 persons during any month must monitor at the same frequency as a like-sized community water system, i.e., the frequency specified in the table, except that the state may reduce the monitoring frequency (in writing) for any month the system serves 1,000 persons or fewer. However, in no case may the state reduce the sampling frequency to less than once every year.

[b]Includes public water systems that have at least 15 service connections, but serve fewer than 25 persons.

Source: *Federal Register*, June 29, 1989 (54 FR 27545).

Table 2-12. Monitoring Requirements Following a Total Coliform-Positive Routine Sample

Number of Routine Samples/Month	Number of Repeat Samples[a]	Number of Routine Samples Next Month[b]
1/month or fewer	4	5/month
2/month	3	5/month
3/month	3	5/month

[a] Number of repeat samples in the same month for each total coliform-positive routine sample.
[b] Except where state has invalidated the original routine sample, or where the state substitutes an onsite evaluation of the problem, or where the state waives the requirement on a case-by-case basis. See 40 CFR 141.21a (b) (5) for more details.

Source: *Federal Register*, June 29, 1989 (54 FR 27546).

Typical costs of laboratory analyses are shown in Table 2-14.

Contact your state drinking water agency for additional information about requirements for sample collection and analysis and reporting.

Surface Water Treatment Requirements

EPA has set treatment requirements to control microbiological contaminants in public water systems using surface water sources (and ground-water sources under the direct influence of surface water). These requirements, effective December 31, 1990, include the following:

- Treatment must remove or inactivate at least 99.9 percent of *Giardia lamblia* cysts and 99.99 percent of viruses.
- All systems must disinfect, and also might be required to filter if certain source water quality criteria and site-specific criteria are not met.
- The regulations set criteria for determining if treatment, including turbidity removal and disinfection requirements, is adequate for filtered systems.
- All systems must be operated by qualified operators as determined by the states.

Systems using surface water must make certain reports to the state documenting compliance with treatment and monitoring requirements.

Detailed guidance on surface water treatment requirements is provided in EPA's *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*.

Table 2-13. Sanitary Survey Frequency for Public Water Systems Collecting Fewer than Five Samples/Month[a]

System Type	Initial Survey Completed by	Frequency of Subsequent Surveys
Community water system	June 29, 1994	Every 5 years
Noncommunity water system	June 29, 1999	Every 5 years[b]

[a]Annual onsite inspection of the system's watershed control program and reliability of disinfection practice is also required by 40 CFR 141.71(b) for systems using unfiltered surface water or ground water under the direct influence of surface water. The annual onsite inspection, however, is not equivalent to the sanitary survey. Thus, compliance with 40 CFR 141.71(b) alone does not constitute compliance with the sanitary survey requirements of this coliform rule (141.21a(d)), but a sanitary survey during a year can substitute for the annual onsite inspection for that year.

[b]For a noncommunity water system that uses only protected and disinfected ground water, the sanitary survey may be repeated every 10 years, instead of every 5 years.

Source: *Federal Register*, June 29, 1989 (54 FR 27546).

Table 2-14. Approximate Commercial Laboratory Costs Per Sample Analysis ($1989)

Turbidity	$ 20
Coliform Bacteria	$ 20
Copper	$ 20
Lead	$ 20
Radium 226/228	$120
8 VOCS (Table 2-10)	$200
Table 2-8 Contaminants	$500

Source: Adapted from Metcalf and Eddy, *A Guide to Water Supply Management in the 1990s*, Wakefield, MA, November 1989.

Systems using surface water are required to filter unless stringent criteria are met.

Chapter Three

Solutions to Drinking Water Treatment Problems: An Overview

This chapter presents an overview of the technologies that a small system should consider for meeting its treatment needs. In addition, it discusses administration and other issues that can be important for small systems, including financial and capital improvements, cooperative arrangements, operator capabilities, and selection of a consulting engineer or equipment vendor. Appendix B presents a checklist of factors that can affect water treatment system performance. While this list is not all-inclusive, it may help a water system operator or manager in determining improvements that may be needed.

The treatment needs of a water system are likely to differ depending on whether the system uses a groundwater or surface water source. Common surface water contaminants include turbidity, microbiological contaminants (*Giardia*, viruses, and bacteria), and low levels of a large number of organic chemicals. Groundwater contaminants include naturally occurring inorganic contaminants (e.g., arsenic, fluoride, radium, radon) and nitrate, and a number of specific organic chemicals (e.g., trichloroethylene) that sometimes occur in relatively high concentrations.[8] Bacteria and viruses can also contaminate relatively shallow ground water (for example, from sewage overflow or seepage into wells and springs, or from surface runoff). *Giardia* cysts are less likely to be found in ground water, but they have contaminated groundwater supplies where sewage or contaminated surface water entered improperly constructed or located wells.[9] Corrosion control is a concern for systems using both surface and ground-water supplies.

Figure 3-1 presents an overview of steps that a small system can follow to determine treatment needs. Tables 3-1 and 3-2 present the contaminants likely to be found in surface water and ground water, and the most suitable treatment technologies for each.

The treatment options available to small systems for filtration, disinfection, organic and inorganic contaminant removal, and corrosion control are also listed in Table 3-3. This table presents the major advantages and disadvantages of each technology. Costs are shown in Table 3-4. Chapters 4 through 7 contain more detailed information about each of these technologies, including their effectiveness in removing specific contaminants in water.

Questions to Consider in Choosing Treatment Technologies

When selecting among the different treatment options, the water system manager must consider a number of factors: regulatory requirements, characteristics of the raw water, configuration of any existing system, cost, operating requirements, availability of nontreatment alternatives, compatibility of the processes currently being used or to be used, waste management, and future needs of the service area. Each of these factors is discussed below.

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[8] Thomas J. Sorg, "Process Selection for Small Drinking Water Supplies," *Proceedings of the Twenty-Third Annual Public Water Supply Engineers Conference: New Directions for Water Supply Design and Operation,* University of Illinois, April 21-23, 1981.

[9] Gunther F. Craun, "Review of the Causes of Waterborne Disease Outbreaks," *Surveillance and Investigation of Waterborne Disease Outbreaks, Health Effects Research Laboratory,* U.S. Environmental Protection Agency, November 1989.

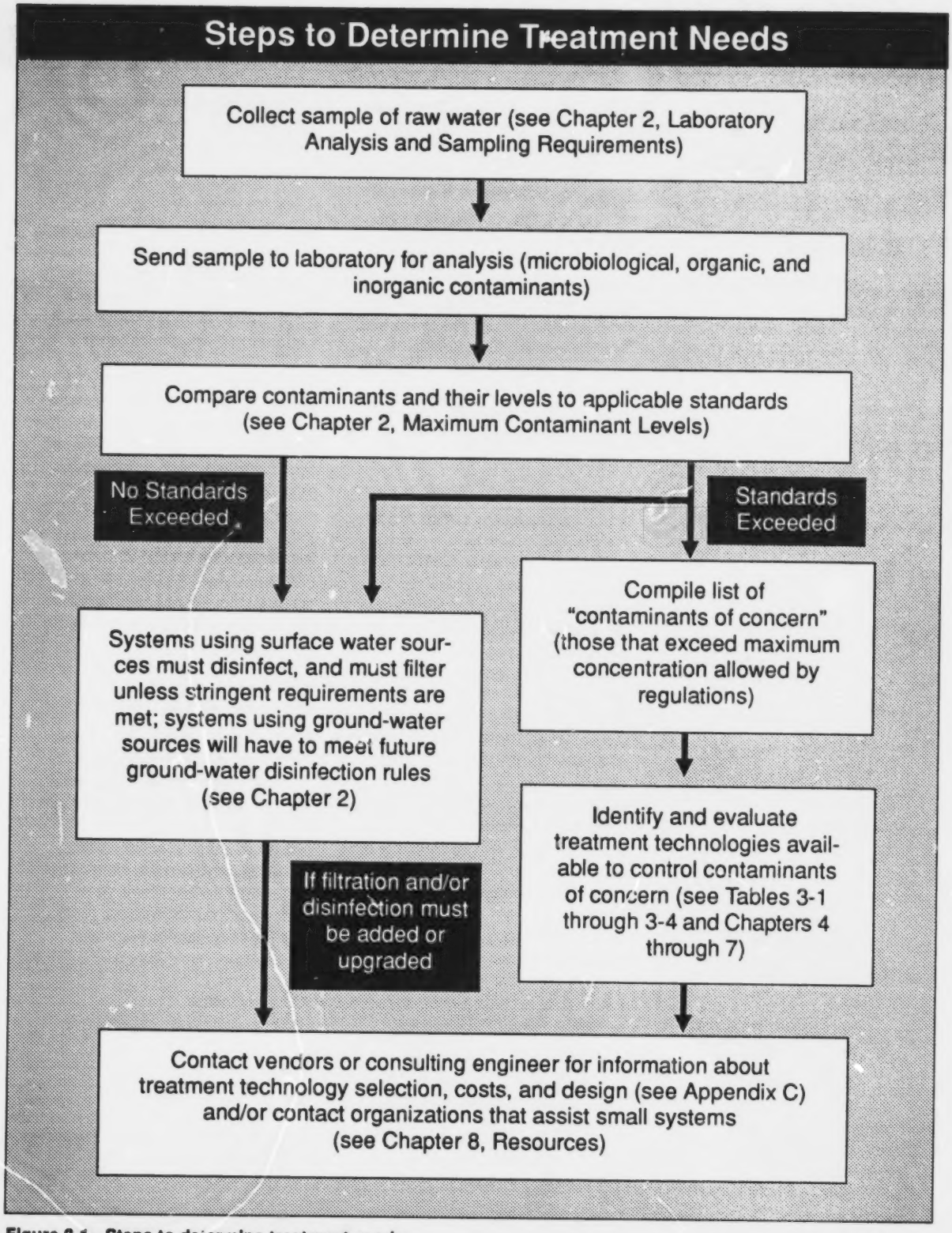

Steps to Determine Treatment Needs
Collect sample of raw water (see Chapter 2, Laboratory Analysis and Sampling Requirements)
Send sample to laboratory for analysis (microbiological, organic, and inorganic contaminants)
Compare contaminants and their levels to applicable standards (see Chapter 2, Maximum Contaminant Levels)
No Standards Exceeded
Standards Exceeded
Systems using surface water sources must disinfect, and must filter unless stringent requirements are met; systems using ground-water sources will have to meet future ground-water disinfection rules (see Chapter 2)
Compile list of "contaminants of concern" (those that exceed maximum concentration allowed by regulations)
If filtration and/or disinfection must be added or upgraded
Identify and evaluate treatment technologies available to control contaminants of concern (see Tables 3-1 through 3-4 and Chapters 4 through 7)
Contact vendors or consulting engineer for information about treatment technology selection, costs, and design (see Appendix C) and/or contact organizations that assist small systems (see Chapter 8, Resources)

Figure 3-1. Steps to determine treatment needs.

Table 3-1. Common Problems and Suitable Treatment Technologies: Ground Water[a]

	Micro-biological	Fluoride	Barium	Nitrate	Radium	Radon	Arsenic	Selenium	Organics
Chlorination	•								
Ozonation	•								
Ultraviolet radiation	•								
Aeration						•			•
Ion exchange			•	•	•		•	•	
Activated alumina		•					•	•	
Coagulation/Filtration							•	•	
Membranes (reverse osmosis and electrodialysis)		•	•	•	•		•	•	
Granular activated carbon (GAC)						•			•
Point-of-use/ Point-of-entry systems	Might be suitable for some very small systems to remove organic or inorganic contaminants.								
Package Plants	Package plants might be available to solve specific inorganic or organic contamination problems.								

[a]In general, "•" indicates the principal function of the treatment technology listed. Many of these technologies, however, have secondary effects in addition to those shown here. (For example, ozone can remove some organic chemicals as well as provide disinfection.)

What Are the Requirements for Drinking Water Supplied by the System?

Federal and state drinking water regulations are the most important factors to consider in developing a water system's treatment goals. The supplier may also choose to consider consumer preferences and nonmandatory guidelines developed by regulatory agencies and professional organizations, such as EPA's Secondary Maximum Contaminant Levels (federally nonenforceable goals for controlling contaminants that affect the aesthetic qualities of drinking water), Health Advisories (guidance values developed by EPA to address immediate or emergency concerns associated with accidents, spills, or newly detected drinking water contamination situations), and American Water Works Association water quality goals.

Are Nontreatment Alternatives Available?

Small water systems might not always have the resources to install a complete treatment system to solve a contamination problem. In such situations, however, a small system might be able to find a new water source. For example, a well can be located in an area distant from the source of contamination.

The development of a new well, however, is only part of the solution. The area around the well must be managed to protect it from future contamination. Establishing a wellhead protection is an appropriate nontreatment alternative.

As another option, a small system can consider cooperating with other systems, such as by buying treated water from a larger utility (see Multicommunity Cooperative Arrangements below).

What Are the Characteristics of the Raw Water?

To determine treatment needs, the system manager must know the quality of the source water—what biological and chemical contaminants are in the water and at what concentrations they are present. Knowledge of other water characteristics, such as pH, temperature, alkalinity, and calcium and magnesium content is useful because of

Table 3-2. Common Problems and Suitable Treatment Technologies: Surface Water[a]

	Turbidity	Microbiological Control	Corrosion Control	Organics
Chlorination		•		
Ozonation		•		
Ultraviolet radiation		•		
Package plants[b]	•	•		
Slow sand filtration	•	•		
Diatomaceous earth filtration	•	•		
Ultrafiltration (membrane filtration)[c]	•	•		
Cartridge filtration[c]	•	•		
Aeration				•
Granular activated carbon (GAC)				•
pH control			•	
Corrosion inhibitors			•	
Point-of-use/ Point-of-entry systems[d]	•		•	•

[a]In general, "•" indicates the principal function of the treatment technology listed. Many of these technologies, however, have secondary effects in addition to those shown here. (For example, ozone can remove some organic chemicals as well as provide disinfection.)

[b]While package plants are most widely used to remove turbidity, color, and microbiological contaminants, package plants are also available that can remove organic and/or inorganic contaminants.

[c]Emerging technology.

[d]Might be suitable for some very small systems that cannot install central treatment. Point-of-use/Point-of-entry systems use a variety of treatment processes, including reverse osmosis, ion exchange, and activated carbon.

their impact on aesthetics and the efficiency of treatment processes.

What Is the Configuration of the Existing System?

The configuration of the existing system can be an important consideration in selecting a treatment option. For example, if a supplier is considering adding a new treatment technology, he or she must know if the existing system is compatible with or adaptable to the new technology. In addition, an existing system's ability to blend treated water with raw water can be important. A system might be able to economize with an expensive technology by treating only part of the total flow, and still meet regulatory requirements that limit the concentration of a contaminant in finished water.

The method of water distribution and its composition (e.g., asbestos-cement pipe, copper, polyvinyl chloride, galvanized, lead) can also be an important factor in selecting a treatment option. For example, corrosion would not be a great concern in systems using polyvinyl chloride (PVC) pipes. The length of the distribution system and how quickly water moves through it can affect requirements for secondary disinfection (to prevent regrowth of microorganisms in the distribution system).

What Are the Costs of the Treatment Options?

The total costs of treatment include one-time capital costs and annual operating and maintenance costs. Each treatment technology has a different mix of capital and operating and maintenance costs. Technologies with high capital costs often have lower operating and maintenance costs (and those with lower capital costs often have higher operating and maintenance costs). Thus, small systems that cannot afford appropriate capital equipment can become saddled with higher operating and maintenance costs.

What Are the Treatment Technology's Operating Requirements?

The most important operational consideration is the consistency of the raw water. The less consistent the raw water quality, the greater the need for monitoring, and the greater the operating complexity of most systems. Thus, a less consistent influent requires a higher level of operator training and attention, and might require greater instrumentation, controls, and automation.

Other important operating considerations include:

- Energy requirements
- Chemical availability, consumption rate, and storage
- Instrumentation and automation
- Preventive maintenance
- Noise
- Aesthetics
- Backup/redundant systems
- Requirements for a startup phase before full removal capacity is achieved
- Cleaning and backwashing requirements
- Distribution system
- Staffing needs
- Operator training requirements
- Process monitoring requirements

How Compatible Are the Processes Used?

To achieve overall treatment goals, all the treatment processes must be compatible. For example, a lower pH is desirable for efficient chlorine disinfection; however, lower pH increases corrosion in the water distribution system. Therefore, a system might maintain a lower pH but use a corrosion inhibitor (described in Chapter 7) to minimize corrosion (or the system might elevate the pH before distribution). All the elements of treatment should be chosen so that they interact as efficiently and effectively as possible.

In addition, using one treatment technology to meet more than one regulatory requirement reduces costs and operating complexity. For example, a system might use reverse osmosis (described in Chapter 7) when both organic and inorganic contaminants are present in raw water. Ozone (described in Chapter 5) can remove organic chemicals as well as provide primary disinfection. Packed tower aeration (described in Chapter 6) can remove both volatile organic chemicals and radon in ground water. It also removes carbon dioxide, thereby raising the pH to a more desirable level for corrosion control. (Aeration, however, can increase dissolved oxygen levels, which can contribute to corrosion.)

What Waste Management Issues Are Involved?

Waste management can be a significant issue for water treatment systems. Most treatment processes concentrate contaminants into a residual stream (brine or sludge) that requires proper management. For example, removal of radon with granular activated carbon can produce a low-level radioactive waste. Water treatment systems must follow federal and state regulations covering the management of wastes. In some cases, this can significantly increase disposal costs for the treatment system.

What Are the Future Needs of the Service Area?

The future of the service and supply area is another important factor in selecting a treatment technology. The supplier can evaluate future demands using population and economic forecasts of the service area. Present and potential water supplies should also be examined to determine their vulnerability to natural and manmade contamination.

Special Issues for Small Systems

Financial/Capital Improvement

Financing water system improvements can be an obstacle for a small system. User charges must be high enough to cover the actual costs of water treatment, analytical work, and distribution. Because costs are spread over fewer people, rate increases have a greater impact on the individual customer than those for large systems.

Most small systems are also at a disadvantage when they attempt to raise funds in the local and national capital markets, since their credit base, market recognition, and financing expertise are usually limited. They might be able to obtain financial assistance through state and federal loan and grant programs. Many states currently have drinking water financial assistance programs. Some states assist small systems in gaining access to capital through low-interest loans from state revolving loan funds, state bond pools, and state-funded bond insurance.

Sources of federal grants and loans for small systems include the Farmers Home Administration (FmHA) and a proposed federal grants program that blends federal grant money with state bond money to provide low-interest loans to small water systems.

Other financing options for small systems include federal revenue sharing and revenue bonds (for municipal systems), loans through the United States Small Business Administration (SBA), and use of tax exempt industrial

Table 3-3. Overview of Water Treatment Technologies[1]

Treatment Requirements	Technological Options to Meet Regulatory Requirements	Stage of Acceptability	Comments
Filtration of surface water supplies to control turbidity and microbial contamination	Slow sand filtration	Established	Operationally simple; low operating cost; requires relatively low turbidity source water
	Package plant filtration	Established	Compact; variety of process combinations available
	Ultrafiltration (Membrane filtration)	Emerging	Experimental, expensive
	Cartridge filtration	Emerging	Experimental, expensive
Disinfection	Chlorine	Established	Most widely used method; concerns about health effects of by-products
	Ozone	Established	Very effective but requires a secondary disinfectant, usually some form of chlorine
	Ultraviolet radiation	Established	Simple, no established harmful by-products, but requires secondary disinfectant, usually some form of chlorine
Organic contamination control	Granular activated carbon	Best Available Technology (BAT)	Highly effective; potential waste disposal issues; expensive
	Packed column aeration	Best Available Technology (BAT)	Highly effective for volatile compounds; potential air emissions issues
	Diffused aeration	Established	Variable removal effectiveness
	Multiple tray aeration	Established	Variable removal effectiveness
	Higee aeration	Experimental	Compact, high energy requirements; potential air emissions issues
	Mechanical aeration	Experimental	Mostly for wastewater treatment; high energy requirements, easy to operate
	Catenary grid	Experimental	Performance data scarce; potential air emissions issues

(continued on next page)

revenue bonds by a private contractor supplying service to a municipality.

Multicommunity Cooperative Arrangements (Regionalization)

In some cases, a small community can share resources with other small communities or a larger community through a cooperative or a regional water supply authority. Multicommunity cooperative arrangements can improve cost effectiveness, upgrade water quality, and result in more efficient operation and management.

A wide range of cooperative approaches is available to the small system, including:

- **Centralizing functions.** A group of small systems working together can centralize functions such as purchasing, maintenance, laboratory services, engineering services, and billing. Several small systems together might be able to afford resources, such as highly

Table 3-3. Overview of Water Treatment Technologies[a] (continued)

Treatment Requirements	Technological Options to Meet Regulatory Requirements	Stage of Acceptability	Comments
Inorganic contamination control	Membranes (Reverse osmosis and electrodialysis)	Established	Highly effective; expensive; potential waste disposal issues
	Ion exchange	Established	Highly effective; expensive; potential waste disposal issues
	Activated alumina	Established	Highly effective; expensive; potential waste disposal issues
	Coagulation/Filtration	Established	May be difficult for very small systems
	Aeration	Established	Preferred technology for radon removal
	Granular Activated Carbon	Established	Highly effective for radon removal; potential waste disposal issues
Corrosion controls	pH control	Established	Potential to conflict with other treatments
	Corrosion inhibitors	Established and emerging	Variable effectiveness depending on type of inhibitor

[a]A variety of package plants are available that can perform one or several treatment functions (i.e., filtration, organic contaminant control, etc.).

Source: U.S. Environmental Protection Agency, Office of Drinking Water and Center for Environmental Research Information, *Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities*, March 1990. EPA 625/4-89-023.

skilled personnel, on a part-time basis.

- **Physically interconnecting existing systems.** Two or more small systems can be connected, or a small system can join a larger system, to achieve the economies of scale available to large systems. This approach might not be feasible in some situations, however, such as in locations where supplies are isolated from each other by long distances or rugged terrain. It is also important to weigh potential disadvantages such as loss of local autonomy, complexities of ensuring equity in each community, and loss of cost effectiveness when distribution lines become too long.
- **Creating a satellite utility.** A satellite utility taps into the resources of an existing larger facility without being physically connected to, or owned by, the larger facility. Resources provided by the larger utility can include technical, operational, or managerial assistance; wholesale treated water; or operation and maintenance responsibility.
- **Creating water districts.** Water districts are formed by county officials and provide for the public ownership of the utilities. The utilities in a district combine resources and/or physically connect systems, so that one or two facilities supply water for the entire district. By forming a water district, privately owned systems become eligible for public grants and loans.
- **Creating county or state utilities.** A county or state government can create a board to construct, maintain, and operate a water supply within its district. Construction and/or upgrading of facilities may be financed through bonds or property assessments.

Operator Capabilities

The level of understanding and technical ability of small systems operators

Table 3-4. Estimated Costs of Drinking Water Treatment Technologies for a 100,000 GPD Plant[a] ($1989)

Technology	Capital Cost	Annual O&M	Total Cost[b] Per 1,000 Gallons
Package Plant Filtration			
Coagulation/Filtration with tube settlers	$176,000	$11,000	$1.73
Pressure depth clarifier/Pressure filter	$206,000	$10,400	$1.90
Pressure depth clarifier/ Pressure filter with GAC adsorber	$246,000	$16,300	$2.47
Other Filtration			
Diatomaceous earth vacuum filter	$103,000	$11,100	$1.27
Diatomaceous earth pressure filter	$106,000	$10,600	$1.26
Slow sand filter: covered	$580,000	$ 7,700	$4.15
Slow sand filter: uncovered	$335,000	$ 7,100	$2.55
Inorganic Contaminant Control			
High pressure reverse osmosis	$275,000	$41,300	$4.03
Low pressure reverse osmosis	$275,000	$29,800	$3.40
Cation exchange	$151,000	$ 8,500	$1.44
Anion exchange	$115,000	$10,300	$1.46
Activated alumina	$104,000	$14,600	$1.47
Organic Contaminant Control			
GAC in pressure vessel	$175,000	$14,400 (6-mo carbon replacement)	$1.92
		$ 9,800 (12-mo carbon replacement)	$1.67
Packed tower aerator	$ 45,100	$ 2,900	$0.45

(continued on next page)

is crucial to the success of the Safe Drinking Water Act (SDWA). The operator's basic knowledge, skills, and training might include the following[10]:

- Sufficient training to protect public health
- Knowledge of all aspects of the distribution system (including maintenance)
- Knowledge of the source water supply (including pump operation)
- Skill to maintain drinking water quality (including water treatment where necessary, plus state and federally required sampling routines)

[10] From National Rural Water Association, *Water System Decision Makers: An Introduction to Water System Operation and Maintenance*, Duncan, OK, 1988.

Table 3-4. Estimated Costs of Drinking Water Treatment Technologies for a 100,000 GPD Plant[a] (continued)

Technology	Capital Cost	Annual O&M	Total Cost[b] Per 1,000 Gallons
Disinfection			
Gas feed chlorination	$ 10,465	$ 3,520	$0.26
Hypochlorite solution	$ 4,080	$ 5,558	$0.33
Pellet feed chlorinators	$ 1,670	$ 4,010	$0.23
Ultraviolet light[c] (57,600 GPD)	$ 25,990	$ 2,090	$0.49
Ozonation-high pressure[c]	$ 39,270	$ 5,074	$0.53

Gallons x 3.785 = liters.

Sources: G.S. Logsdon, T.J. Sorg, and R.M. Clark, *Cost and Capability of Technologies for Small Systems*, Drinking Water Research Division, Risk Reduction Engineering Laboratory, EPA, Cincinnati, OH, May 1989.

R.C. Gumerman et al., *Estimation of Small System Water Treatment Costs*, Final Report, Culp/Wesner/Culp, Santa Ana, CA, November 1984.

U.S. Environmental Protection Agency, Office of Drinking Water, *Microorganism Removal for Small Water Systems*, Washington, DC, June 1983. EPA 570/9-83-012.

[a]Construction costs generally include manufactured equipment, concrete, steel, labor, pipes and valves, electrical equipment and instrumentation, housing, site evacuation, some other site work, general contractor's overhead and profit, engineering costs, financial and administrative costs, and interest costs during construction. Construction costs do not include land costs, legal fees, interface piping, roads, and certain other site work. O&M costs generally include annual energy, labor, and chemical costs. Construction costs can vary depending on specific data characteristics. O&M costs can vary, up to plus or minus 100 percent for some technologies, depending on such variables as feed water characteristics, flow rate, and chemical dosage requirements.

[b]Costs include capital costs annualized at 10 percent interest over 20 years plus annual O&M costs. Average flow assumed at 50 percent of design flow.

[c]Costs for ultraviolet and ozone disinfection reflect those for primary disinfection only. A secondary disinfectant is necessary to maintain a residual in the distribution system. The costs of secondary disinfection are not included in the table.

- Knowledge of sources of contamination and methods used to manage these sources.
- Knowledge and understanding of energy sources
- Understanding of emergency procedures
- Knowledge of state and federal regulations
- Recordkeeping skills
- A willingness to participate in continuing education programs

Without a properly trained operator, system operation and water quality will suffer. The small system might have difficulty attracting skilled staff because of economic constraints. In addition, many small system operators have multiple duties, such as maintaining the grounds or performing other related public works duties, and might not have the opportunity to specialize and develop expertise in drinking water treatment.

Operator capability can also limit the technology options available to a small system: a technology that works well in a large city might require more operator training than the small system can obtain.

Small systems might be able to obtain qualified plant operators by contracting the services of personnel from a larger neighboring utility, government agency, service company, or consulting firm. Small systems can also use the National Rural Water Association for technical assistance (see Chapter 8, Resources).

A "circuit rider" approach, in which service is provided to several systems that cannot individually afford a trained operator, can also be used. The circuit rider attends to a number of treatment systems, and his or her salary is shared among them. The circuit rider can directly operate the plants or provide technical assistance to individual plant operators through on-the-job training and supervision.

Another source of training is the treatment equipment manufacturer. When treatment equipment is purchased, vendors should supply startup assis-

tance and training, as well as detailed operation and maintenance manuals.

Additional training resources for small systems are listed in Chapter 8.

Selecting a Consulting Engineer/ Equipment Vendor

In some cases, a small community might need to use the services of a consulting engineer or equipment vendor to design a treatment system. Consultants should have proven experience in solving problems for small systems. Appendix B provides some guidelines for selecting a consultant.

Using a Point-of-Use/Point-of-Entry (POU/POE) System

A number of point-of-use (POU) and point-of-entry (POE) systems are available from a large number of manufacturers. Types of systems include those using reverse osmosis, activated alumina, and ion exchange. In certain situations, POU/POE devices can be a cost-effective solution when a very small community cannot afford central treatment for a contaminant, such as an organic chemical or fluoride. For example, with state approval, several small communities (25 to 200 people) in Arizona installed home systems using activated alumina to remove fluoride. A manufacturing/engineering company on contract with one community provides and maintains all the systems.[11]

In addition to home devices, some very small systems (such as trailer parks) might be able to install a treatment system at the point of entry and blend resulting treated waters with water not treated with the POE device.

A public water supplier must monitor and ensure the quality of water treatment, whether it provides central treatment or decentralized treatment through POU/POE devices. The supplier should check with the state drinking water agency or regional EPA office to determine whether POU/POE devices are appropriate.

[11] Thomas Sorg, "Process Selection for Small Drinking Water Supplies," *Proceedings of the Twenty-Third Annual Public Water Supply Engineers' Conference: New Directions for Supply Design and Operation*, University of Illinois, April 21-23, 1981.

Chapter Four

Filtration Technologies for Small Systems

Filtration is the process of removing suspended solids from water as the water passes through a porous bed of materials. Natural filtration removes most suspended matter from ground water as the water passes through porous layers of soil into aquifers (water-bearing layers under the ground). Surface waters, however, are subject to runoff and other sources of contamination, so these waters must be filtered by a constructed treatment system.

The solids removed during filtration include soil and other particulate matter from the raw water, oxidized metals, and microorganisms. Filtration can be used to remove many microorganisms, some of which might be resistant to disinfection. Filtration also prevents suspended material (measured as turbidity) from interfering with later treatment processes, including disinfection. Filtration combined with disinfection provides a "double barrier" against waterborne disease caused by microorganisms.

The filtration process usually works by a combination of physical and chemical processes. Mechanical straining removes some particles by trapping them between the grains of the filter medium (such as sand). A more important process is adhesion, by which suspended particles stick to the surface of filter grains or previously deposited material. Figure 4-1 illustrates these two removal mechanisms. Biological processes are also important in slow sand filters. These filters form a filter skin containing microorganisms that trap and break down algae, bacteria, and other organic matter before the water reaches the filter medium itself.

Processes Preceding Filtration

Even when treating low turbidity water, filtration is preceded by some form of pretreatment. Several processes may precede filtration (Figure 4-2):

- **Chemical feed and rapid mix.** Chemicals may be added to the water to improve the treatment processes that occur later. These chemicals may include pH adjusters and coagulants. (Coagulants are chemicals, such as alum, that neutralize positive or negative charges on small particles, allowing them to stick together and form larger, more easily removed particles.) A variety of

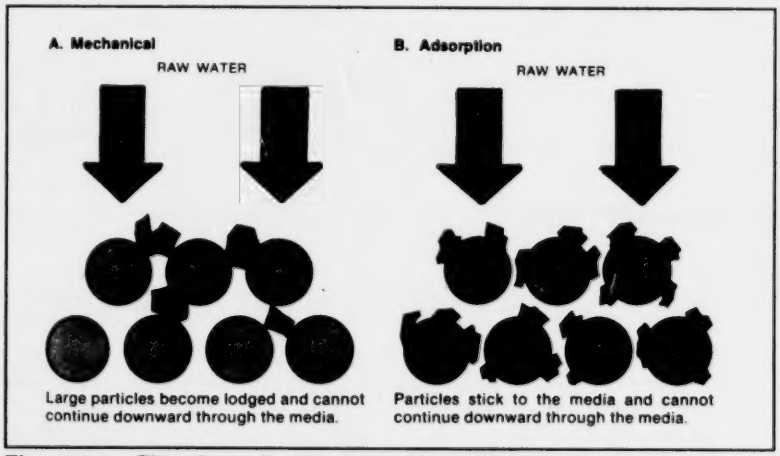

A. Mechanical
RAW WATER
Large particles become lodged and cannot continue downward through the media.
B. Adsorption
RAW WATER
Particles stick to the media and cannot continue downward through the media.

Figure 4-1. Filtration primarily depends on physical and chemical mechanisms to remove particles from water. (Reprinted from *Introduction to Water Treatment,* Vol. 2, by permission. Copyright 1984, American Water Works Association.)

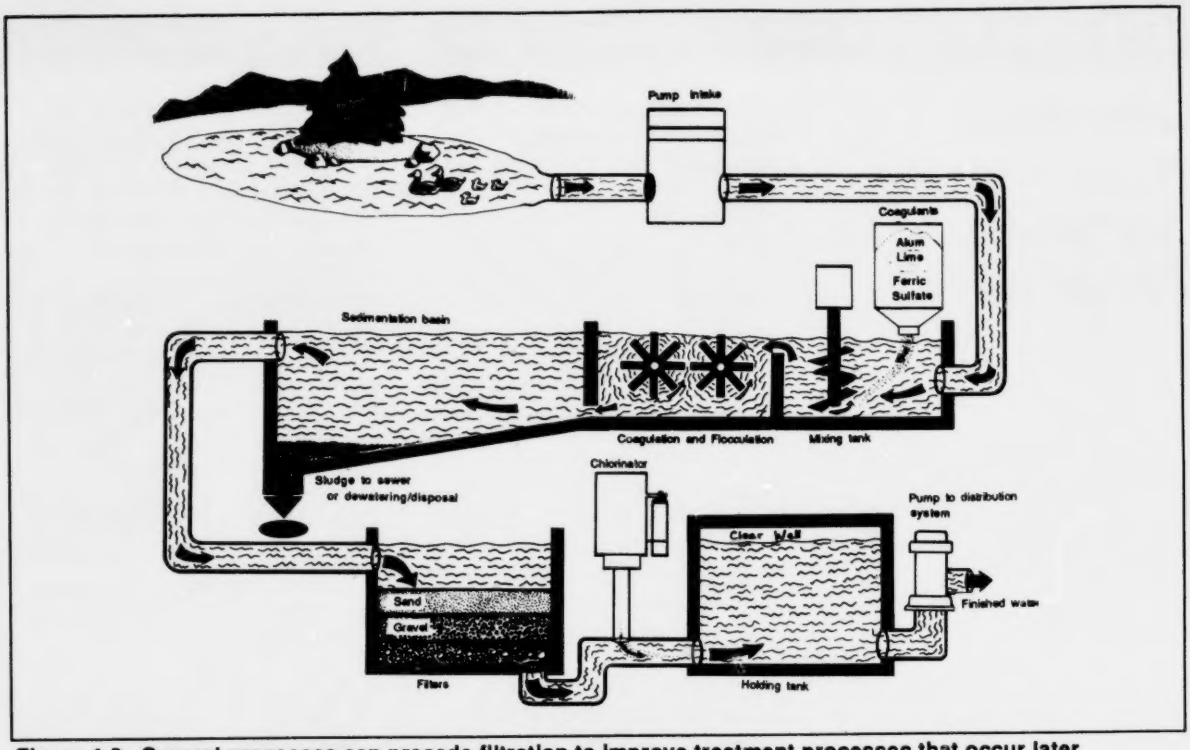


Figure 4-2. Several processes can precede filtration to improve treatment processes that occur later.

devices, such as baffles, hydraulic jumps, static mixers, impellers, and in-line jet sprays can be used to mix the water and distribute the chemicals evenly.

- **Flocculation.** In this process, which follows rapid mixing, the chemically treated water is sent into a basin where the suspended particles can collide and form heavier particles called floc. Gentle agitation and appropriate detention times (the length of time water remains in the basin) facilitate this process.
- **Sedimentation.** Following flocculation, a sedimentation step may be used. During sedimentation, the velocity of the water is decreased so that the suspended material (including flocculated particles) can settle out of the water stream by gravity. Once settled, the particles combine to form a sludge that is later removed from the clarified supernatant water.

Filtration processes can include only one of these pretreatment procedures or all of them.

Choosing a Filtration Technology

Conventional filtration, which includes coagulation with the addition of chemicals, rapid mixing, flocculation and sedimentation, and granular media filtration, is the most versatile system for treating raw water that is variable in quality. However, a conventional filtration plant is usually neither appropriate nor economically feasible for very small systems. *Package plants* are one available cost-effective alternative when automatic chemical feed control systems simplify operation.

Other filtration technologies that can be more suitable for small systems are *slow sand filtration* and *diatomaceous earth filtration. Membrane filtration* and *cartridge filtration* are two emerging technologies that are suitable for small systems. Table 4-1 presents the advantages and disadvantages of these technologies. Table 4-2 shows the removal capacities (percentages that are effectively removed) of *Giardia* cysts and viruses for these four technologies. Filtration technologies for small systems are described in more detail below.

Slow Sand Filtration

Slow sand filtration, first used in the United States in 1872, is the oldest type of municipal water filtration. A slow sand filter consists of a layer of fine sand supported by a layer of graded gravel. Slow sand filtration does not require extensive active control by an operator. This can be important for a small system in which an operator has several responsibilities.

Slow sand filters require a very low application or filtration rate (.022 cubic meters per hour per square centimeter [0.015 to 0.15 gallons per minute per square foot of bed area], depending on the gradation of the filter media and the quality of the raw water). The removal action includes a biological process in addition to physical and

Table 4-1. Advantages and Disadvantages of Filtration Technologies

Filtration Technology	Advantages	Disadvantages
Slow sand	Operational simplicity and reliability Low cost Ability to achieve greater than 99.9 percent *Giardia* cyst removal	Not suitable for water with high turbidity Maintenance needs of filter surfaces
Diatomaceous earth	Compact size	Most suitable for raw water with low bacterial counts and low turbidity (less than 10 NTU)
	Simplicity of operation	Requires coagulant and filter aids for effective virus removal
	Excellent cyst and turbidity removal	Potential difficulty in maintaining complete and uniform thickness of diatomaceous earth on filter septum
Membrane	Extremely compact	Little information available to establish design criteria or operating parameters
	Automated	Most suitable for raw water with less than 1 NTU; usually must be preceded by high levels of pretreatment
		Easily clogged with colloids and algae
		Short filter runs
		Concerns about membrane failure
		Complex repairs of automated controls
		High percent of water lost in backflushing
Cartridge	Easy to operate and maintain	Little information available to establish design criteria and operating parameters
		Can be quickly clogged by algae and colloids
		Requires low turbidity influent
		Can require relatively large operating budget

Table 4-2. Removal Capacities of Four Filter Options

Filtration Options	Achievable *Giardia* Cyst Levels (percent Removal)	Achievable Virus Levels
Slow sand	99.99	99.9999
Diatomaceous earth	99.99[a]	99.95[b]
Membrane	100	Very low
Cartridge	>99	Little data available

[a]Aided by coagulation.
[b]With filter aid.

Source: U.S. Environmental Protection Agency, Office of Drinking Water and Center for Environmental Research Information, *Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities*, March 1990. EPA 625/4-89-023.

chemical ones. A sticky mat of suspended biological matter, called a "schmutzdecke," forms on the sand surface, where particles are trapped and organic matter is biologically degraded. Water applied to slow sand filters is usually not prechlorinated, since the chlorine destroys the organisms in the schmutzdecke that help remove microbiological, organic, and other contaminants. (Sometimes water is prechlorinated and then dechlorinated before slow sand filtration.)

Water with high turbidity can quickly clog the fine sand in these filters. Water is generally applied to slow sand filters without any pretreatment when it has turbidity levels lower than 10 NTU (nephelometric turbidity units). The upper turbidity limit for slow sand filters is between 20 and 50 NTU. When slow sand filters are used with surface waters having widely varying turbidity levels, they can be preceded by infiltration galleries or roughing filters, such as upflow gravel filters, to reduce turbidity.

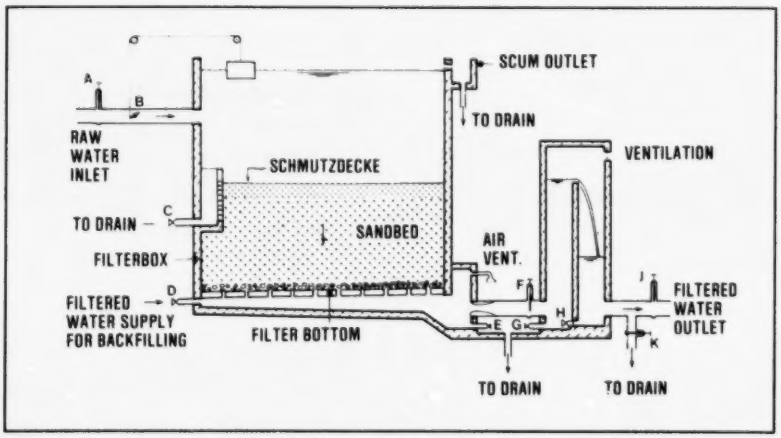


Figure 4-3. Slow sand filter. (Source: International Reference Centre for Community Water Supply and Sanitation, *Technology of Small Water Supply Systems in Developing Countries*, WHO Collaborating Centre, The Hague, The Netherlands, 1982.)

Because of the absence of coagulation, slow sand filtration is limited to certain types of raw water quality. Slow sand filters do not provide very good removal of organic chemicals, dissolved inorganic substances such as heavy metals, and trihalomethane precursors (chemical compounds, formed when natural organic substances dissolve in water, that might form THMs when mixed with chlorine). Also, waters with very fine clays are not easily treated using sand filters. High algae blooms will result in short filter runs.

A slow sand filter must be cleaned when the fine sand becomes clogged (as measured by the head loss). The length of time between cleanings can range from several weeks to a year, depending on the raw water quality. Cleaning is performed by scraping off the top layer of the filter bed. A "ripening period" of 1 to 2 days is required for scraped sand to produce a functioning biological filter. The filtered water quality is poor during this time, and the filtered water must be wasted. Extended cleaning periods require redundant or standby systems. In some small slow sand filters, geotextile filter material is placed in layers over the surface. A layer of filter cloth can be removed periodically so that the upper sand layer requires less frequent replacement.

In climates subject to below-freezing temperatures, slow sand systems usually must be housed. Unhoused filters in harsh climates develop an ice layer that prevents cleaning. Thus, uncovered slow sand filters will operate effectively only if turbidity levels of the influent (water flowing in) are low enough for the filter to operate through the winter months without cleaning. In warm climates, a cover over the slow sand filter may be needed to reduce algae growth within the filter. Figure 4-3 shows a typical slow sand system.

In addition to maintenance, slow sand filters require:

- Daily inspection
- Control valve adjustment
- Daily turbidity monitoring

Slow sand filters can achieve 91 to 99.99 percent removal of viruses and greater than 99.9 percent removal of *Giardia* cysts.

Package slow sand filters, constructed from lightweight materials and transported for local installation, have been used successfully in small rural communities in developing countries.[12] These might be appropriate where community size is less than 1,000 people and conventional construction of a slow sand filter would be too slow or inconvenient.

Diatomaceous Earth Filtration

Diatomaceous earth (DE) filtration, widely used for filtering swimming pool waters, has also been used successfully to remove turbidity and *Giardia* cysts from drinking water. Advantages of DE filters include compact size, simplicity of operation, and excellent turbidity removal. They are most suited for water systems with low turbidity (less than 10 NTU) and low bacterial counts.

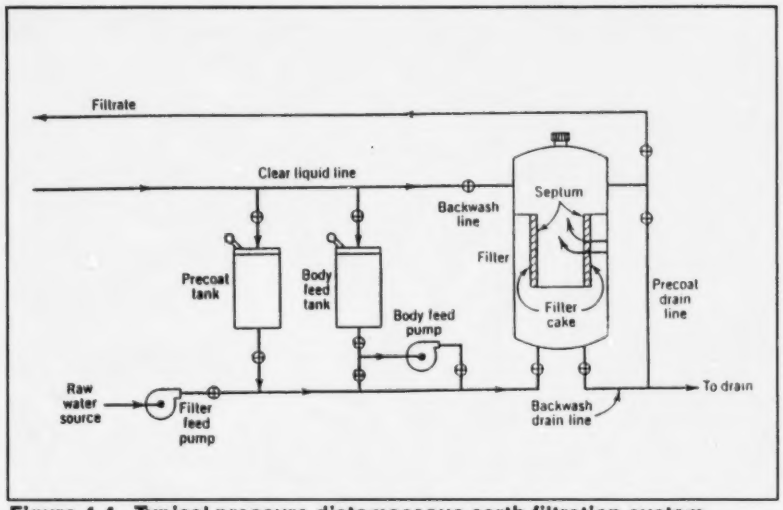


Figure 4-4. Typical pressure diatomaceous earth filtration system.

DE filters (Figure 4-4) use a very thin layer of diatomaceous earth as a filter material (3.2 to 6.4 mm [1/8 to 1/4 in.]) which is coated on a porous septum or filter element. An appropriate grade of diatomaceous earth should be used. (Grades vary from fine to coarse, with fine grades removing smaller particle sizes but producing shorter filter runs). The septum is placed in a pressure vessel or operated under a vacuum in an open vessel. Additional diatomaceous earth ("body feed") is also added to the influent water during the filtration process to prolong the filter run. Higher body feed doses are needed for higher concentrations of suspended solids in the raw water. When the filter becomes plugged, it is backwashed and agitated so that the diatomaceous earth falls off the septum and is flushed from the filter tank.

Operation and maintenance of diatomaceous earth filters require:

- Preparing slurries of filter body feed and precoat diatomaceous earth.
- Adjusting body feed dosages for effective turbidity removal.
- Periodic backwashing, every 1 to 4 days, depending on raw water quality.
- Disposing of spent filter cake.
- Periodically inspecting the filter septum for cleanliness and damage.
- Verifying the effluent quality.
- Maintaining pumps, mixers, feeders, valves, and piping needed for precoat and body feed operations.

DE filters can effectively remove *Giardia* cysts, algae, and asbestos, and the fine grades of diatomaceous earth can remove bacteria. These filters require, however, that the water be pretreated with coagulating chemicals and special filter aids to effectively remove viruses.

Plain diatomaceous earth treatment (without the use of a coagulant) does not provide good removal of very fine particles. DE filters also are not capable of removing dissolved substances, including color-causing materials. Excessive suspended matter and algae in the raw water can cause short filter runs.

[12] B.J. Lloyd, M. Pardon, D. Wheeler, *Rural Water Treatment Package Plant: Final Report for the U.K. Overseas Development Administration*, July 1986. DelAgua, P.O. Box 92, Guildford, GU2STQ, England.

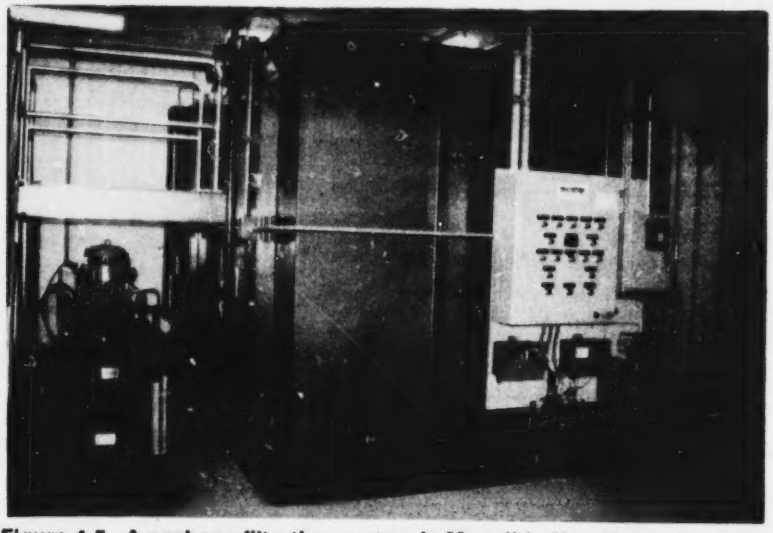


Figure 4-5. A package filtration system in Meredith, New Hampshire.

Package Plants

Package plants (Figure 4-5) are treatment units that are assembled in a factory, skid mounted, and transported to the treatment site or that are transported as component units to the site and then assembled. They are most widely used to treat surface water supplies for removal of turbidity, color, and coliform organisms with filtration processes, but package plants that can remove inorganic and/or organic contaminants are also available. Package plants are often used to treat small community water supplies, as well as supplies in recreational areas, state parks, construction sites, ski areas, military installations, and other areas not served by municipal supplies.

Package plants can vary widely in their design criteria and operating and maintenance requirements. The most important factor to consider in selecting a package plant is the nature of the influent, including characteristics such as temperature, turbidity, and color levels. Pilot tests (tests that evaluate treatment processes and operations on a small scale to obtain performance criteria) might be necessary before a final system can be selected. The package treatment equipment manufacturer can often perform these tests.

Package plants can be (and usually are) designed to minimize the amount of day-to-day attention required to operate the equipment. Their operation and maintenance are simplified by automated devices such as effluent turbidimeters connected to chemical feed controls and other operating parameters, such as backwashing. Chemical feed controls are especially important for plants without full-time operators or with variable influent characteristics. Even with these automated devices, however, the operator needs to be properly trained and well acquainted with the process and control system.

Figure 4-6 depicts a package plant. The three basic types of package water treatment systems are:

- **Conventional package plants.** These contain the conventional processes of coagulation, flocculation, sedimentation, and filtration.
- **Tube-type clarifier package plants.** These use tube settlers to reduce settling detention time (the average length of time water remains in the tank or chamber).
- **Adsorption clarifier package plants.** These use a contact "bed" with plastic bead media (an adsorption clarifier) to replace the flocculation and sedimentation basin, thereby combining these two steps into one. A mixed media filter (a filter with a coarse-to-fine gradation of filter media or several types of filter media) completes the treatment.

Package plants can effectively remove turbidity and bacteria from surface water of fairly consistent quality, provided that they are run by competent operators and are properly maintained. Package plants also can be designed to remove dissolved substances from the raw water, including color-causing substances and trihalomethane precursors. However, when the turbidity of the raw water varies a great deal, these plants require a high level of operational skill and operator attention.

Membrane Filtration (Ultrafiltration)

Membrane filtration, also known as ultrafiltration, uses hollow fiber membranes to remove solids from water. It can be an attractive option for small systems because of its small size and automated operation, and it does not require coagulation as a pretreatment step.

Many membrane systems are designed as skid-mounted units. Figure 4-7 shows an example of this type of membrane system.

Membrane filtration systems can remove bacteria, *Giardia*, and some viruses. They are most suitable for polishing water that has already been treated by other methods, or for drinking water supplies with turbidity of less than 1 NTU. Fouling of the fibers is the major problem preventing widespread application of this technology.

Traditional membrane filters work by feeding water to the inside of the fiber membrane, with the filtrate (filtered water) emerging on the outside of the membrane. State-of-the-art membrane

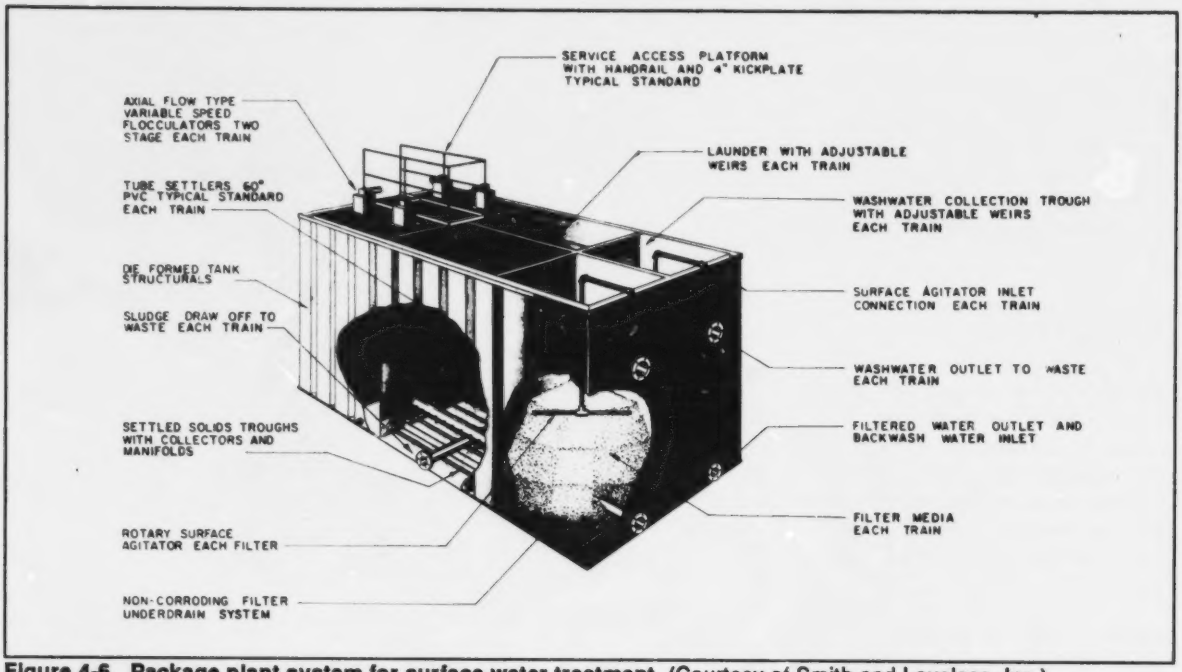

SERVICE ACCESS PLATFORM WITH HANDRAIL AND 4" KICKPLATE TYPICAL STANDARD
AXIAL FLOW TYPE VARIABLE SPEED FLOCCULATORS TWO STAGE EACH TRAIN
LAUNDER WITH ADJUSTABLE WEIRS EACH TRAIN
TUBE SETTLERS 60° PVC TYPICAL STANDARD EACH TRAIN
WASHWATER COLLECTION TROUGH WITH ADJUSTABLE WEIRS EACH TRAIN
DIE FORMED TANK STRUCTURALS
SURFACE AGITATOR INLET CONNECTION EACH TRAIN
SLUDGE DRAW OFF TO WASTE EACH TRAIN
WASHWATER OUTLET TO WASTE EACH TRAIN
SETTLED SOLIDS TROUGHS WITH COLLECTORS AND MANIFOLDS
FILTERED WATER OUTLET AND BACKWASH WATER INLET
FILTER MEDIA EACH TRAIN
ROTARY SURFACE AGITATOR EACH FILTER
NON-CORRODING FILTER UNDERDRAIN SYSTEM

Figure 4-6. Package plant system for surface water treatment. (Courtesy of Smith and Loveless, Inc.)

filters pass influent to either the inside or outside of the membrane. The hollow fiber membranes are contained in a pressure vessel or cartridge. The contaminants collect on the end of the hollow fiber and are discharged to waste by a reversal of water flow. Ultrafiltration membranes exclude particles larger than 0.2 microns.

The membrane filter system must be cleaned to clear the hollow fibers. This is done by backflushing and chemical cleaning or by air pressure. Some manufacturers have developed self-cleaning systems to extend the time between chemical cleanings.

One major concern about membrane filters is the potential for membrane failure. The failure of a membrane should trigger an operational shutdown or an alarm to the operator.

A diagram of a sample membrane system is shown in Figure 4-8.

Cartridge Filtration

Cartridge filters consist of ceramic or polypropylene filter elements that are packed into pressurized housings. They use a physical process for filtration—straining the water through porous media. Cartridge filtration systems require raw water with low turbidity.

Cartridge filters are easy to operate and maintain, making them suitable for small systems with low turbidity influent. Skilled personnel are not needed; personnel are needed only for daily operation and general maintenance (cleaning and cartridge re-

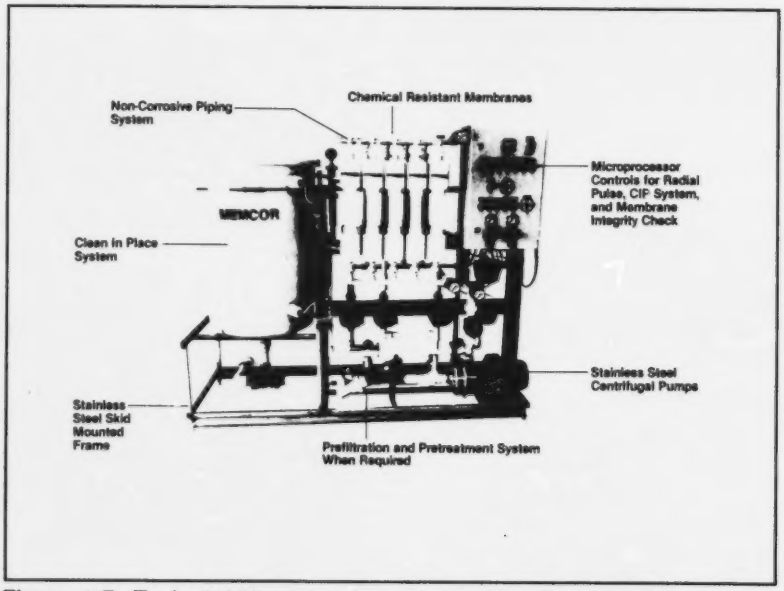

Non-Corrosive Piping System
Chemical Resistant Membranes
Microprocessor Controls for Radial Pulse, CIP System, and Membrane Integrity Check
MEMCOR
Clean in Place System
Stainless Steel Centrifugal Pumps
Stainless Steel Skid Mounted Frame
Prefiltration and Pretreatment System When Required

Figure 4-7. Typical skid-mounted membrane filtration assembly.

placement). Ceramic filters may be cleaned and used for repeated filter cycles. Polypropylene cartridges become fouled relatively quickly and must be replaced with new units. Although these filter systems are operationally simple, they are not automated and can require relatively large operating budgets.

Cartridge filtration systems sometimes use "roughing filters" as pretreatment to remove large solids. Prechlorination is recommended to prevent the growth of microorganisms on the filters. (However, this should be avoided if the raw water contains organic substances that can contribute to formation of trihalomethanes) Except for a disinfectant, no other chemicals need to be added.

Little information is available concerning the effectiveness of cartridge filters for virus removal.

Innovative Filtration Technologies

Several other simple low-cost filtration methods might be appropriate for some small systems. For example, a system developed by 3M Company using disposable filter bags made of polypropylene fibers (Figure 4-9) can remove *Giardia* cysts from drinking water supplies. Small systems in several states have successfully used these filters with disinfection for treatment of water from surface sources.

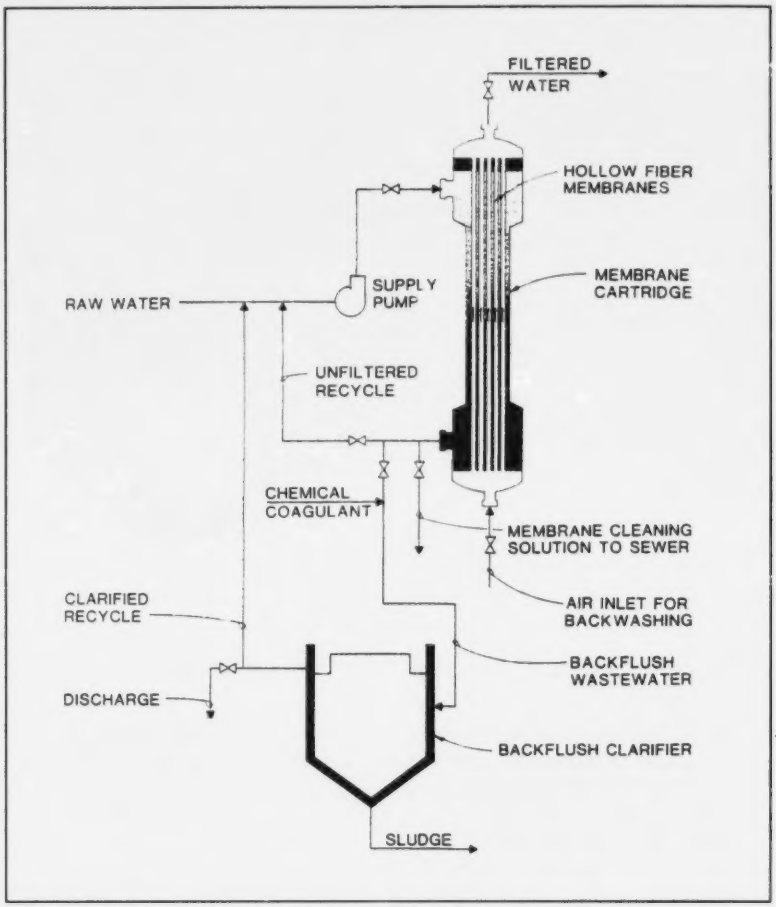


Figure 4-8. Flow sheet of membrane filtration system.

Figure 4-9. Simple filter bag system removes particles ranging from 1 to 4 microns. (Courtesy of 3M Filtration Products)

Chapter Five

Disinfection

Disinfection is the treatment process used to destroy disease-causing organisms in a water supply. ***Primary disinfection*** **refers to the part of the treatment process that provides the necessary inactivation of** *Giardia* **cysts, bacteria, and viruses in source water. Secondary disinfection refers to maintenance of a disinfectant residual which prevents the regrowth of microorganisms in the water distribution system. Systems must disinfect surface water according to the requirements of the Surface Water Treatment Rule (see Chapter 2).**

Chlorination (the addition of chlorine) is the most common method of disinfecting drinking water. Other disinfectants that small systems might want to consider are ozone and ultraviolet (UV) radiation. Table 5-1 summarizes the advantages and disadvantages of these three disinfectants. The preferred application point for each disinfectant is shown in Table 5-2.

Chlorination

When chlorination is performed properly, it is a safe, effective, and practical way to destroy disease-causing organisms. It also provides a stable residual (disinfectant remaining in the water) to prevent regrowth in the distribution system. However, under certain conditions, chlorine can combine with remaining organic materials in the water to produce potentially harmful by-products such as trihalomethanes. (See Disinfection By-Products and Strategies for Their Control below.)

Complex chemical reactions occur when chlorine is added to water, but these reactions are not always obvious. For example, a chlorine taste or odor in finished water is sometimes the result of *too little* chlorine rather than too much. It is important for operators to understand basic chlorination chemistry and the factors affecting chlorination efficiency. These topics are covered thoroughly in many water supply textbooks. (See Chapter 8, Resources.)

Disinfection Terminology

When chlorine is fed into water, it reacts with any substances that exert a "chlorine demand." Chlorine demand is a measure of the amount of chlorine that will combine with impurities and therefore will not be available to act as a disinfectant. Impurities that increase chlorine demand include natural organic materials, sulfides, ferrous iron, and nitrites.

Chlorine can also combine with ammonia or other nitrogen compounds to form chlorine compounds that have some disinfectant properties. These compounds are called combined available chlorine residual. ("Available" means available to act as a disinfectant.)

The uncombined chlorine that remains in the water after any combined residual is formed is called free available chlorine residual. Free chlorine is a much more effective disinfectant than combined chlorine.

Free chlorine is not available for disinfection unless the chlorine demand of the raw water is satisfied. When chlorine dosage exceeds the "breakpoint"—the point at which chlorine demand is satisfied—additional chlorine will result in a free available chlorine residual. The chlorine dosage needed to produce a free residual varies with the quality of the water source.

Factors Affecting Chlorination Efficiency

Five factors are important to successful chlorination: *concentration* of free chlorine, *contact time, temperature, pH,* and *turbidity levels.*

The effectiveness of chlorination is directly related to the *concentration* of free available chlorine and the *contact time.* Contact time is the length of time

Table 5-1. Advantages and Disadvantages of Three Disinfectants

Disinfectant	Advantages	Disadvantages
Chlorine	Very effective; has a proven history of protection against waterborne disease. Widely used. Variety of possible application points. Inexpensive. Appropriate as both primary and secondary disinfectant. Operators can easily test for chlorine residual throughout the water system.	Potential for harmful by-products under certain conditions
Ozone	Very effective. Minimal harmful by-products identified to date.	Relatively high cost. More complex operations because it must be generated on site. **Requires a secondary disinfectant.**
Ultraviolet radiation	Very effective for viruses and bacteria. Readily available. No known harmful residuals. Simple operation and maintenance for high quality waters.	Inappropriate for surface water **Requires a secondary disinfectant.**

Source: Adapted from U.S. Environmental Protection Agency, Office of Drinking Water and Center for Environmental Research Information, *Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities,* March 1990. EPA 625/4-89-023.

the organisms are in physical contact with the chlorine. If the chlorine concentration is decreased, then the contact time must be increased.

The lower the *pH*, the more effective the disinfection. The pH also affects corrosivity and formation of disinfection by-products. The effects of pH should be considered along with disinfection effectiveness.

The higher the *temperature*, the faster the disinfection rate. The treatment system operator usually cannot control the temperature, but then must increase the contact time or dose at lower temperatures.

Chlorine (or any disinfectant) is effective only if it comes into contact with the organisms to be killed. High *turbidity levels* can prevent good contact and protect the organisms. Turbidity should be reduced where necessary through coagulation, sedimentation and filtration, or other treatment methods.

Chlorination Chemicals

Chlorine is available as a liquid (sodium hypochlorite), a solid (calcium hypochlorite), or a gas. Small systems most commonly use sodium hypochlorite or calcium hypochlorite, because they are simpler to use and have less extensive safety requirements than gaseous chlorine. The choice of a chlorination system—liquid, solid, or gas—depends on a number of site-specific factors, including:

- Availability and cost of the chlorine source chemical
- Capital cost of the chlorination system
- Operation and maintenance costs of the equipment
- Location of the facility
- Availability of electricity at the treatment site
- Operator skills
- Safety considerations

Disinfection with Sodium Hypochlorite Solution

Sodium hypochlorite (chlorine in liquid form) is available through chemical and swimming pool equipment suppliers, usually in concentrations of 5 to 15 percent chlorine. It is easier to handle than gaseous chlorine or calcium hypochlorite. Sodium hypochlorite is very corrosive, however, and should be handled and stored with care and kept away from equipment that can be damaged by corrosion.

A basic liquid chlorination system or hypochlorinator (Figure 5-1) includes two metering pumps (one serving as a standby), a solution tank, a diffuser (to inject the solution into water), and

Table 5-2. Desired Points of Disinfectant Application[a]

Disinfectant	Point of Application
Chlorine	Towards the end of the water treatment process so that water is as clarified (organic free) as possible, thereby minimizing THM formation and providing secondary disinfection.
Ozone	Prior to the rapid mixing step in all treatment processes. In addition, sufficient time for biodegradation of the oxidation products of the ozonation of organic compounds is recommended prior to secondary disinfection.
Ultraviolet radiation	Towards the end of the water treatment process to minimize the presence of other contaminants that interfere with this disinfectant and to minimize operating problems.

[a]In general, disinfectant dosages will be lessened by placing the point of application towards the end of the water treatment process because of the lower levels of contaminants there to interfere with efficient disinfection. However, water plants with short detention times in clear wells and with nearby first customers might be required to move their point of disinfection upstream to attain the appropriate CT value (see page 44) under the Surface Water Treatment Rule.

Source: U.S. Environmental Protection Agency, Office of Drinking Water and Center for Environmental Research Information, *Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities,* March 1990. EPA 625/4-89-023.

tubing. Hypochlorinators, used with chlorine in either liquid or solid form, are discussed in more detail under Hypochlorination Equipment below.

Sodium hypochlorite solutions lose their disinfecting power during storage, and should be stored in a cool, dry, dark area. No more than a 1-month supply should be purchased at one time, to prevent loss of available chlorine.

Sodium hypochlorite solution is more costly per pound of available chlorine than chlorine gas. It also does not contain the high concentration of chlorine available from chlorine gas. However, the handling and storage costs are lower than for chlorine in its gaseous form.

Disinfection with Solid Calcium Hypochlorite

Calcium hypochlorite is a white solid that can be purchased in granular, powdered, or tablet form. It contains 65 percent available chlorine and is easily dissolved in water. The chemical is available in 1-, 2-, 4-, and 16-kg (2-, 5-, 8-, and 35-pound) cans and 360-kg (800-pound) drums.

When packaged, calcium hypochlorite is very stable, so that a year's supply can be bought at one time. However, it is hygroscopic (readily absorbs moisture) and reacts slowly with moisture in the air to form chlorine gas. Therefore, shipping containers must be emptied completely or carefully resealed.

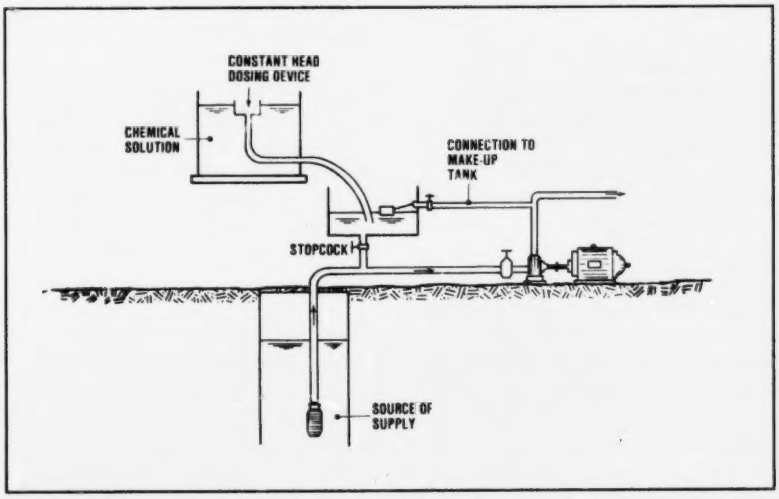


Figure 5-1. Simple liquid chlorination disinfection system for ground-water supplies. Source water is pumped to a service reservoir into which a chlorine solution is dosed. (Source: International Reference Centre for Community Water Supply and Sanitation, *Technology of Small Water Supply Systems in Developing Countries,* WHO Collaborating Centre, The Hague, The Netherlands, 1981.)

Calcium hypochlorite is dissolved in water in a mixing tank. The resulting solution is stored in and fed from a stock solution vessel made of corrosion-resistant materials, such as plastic, ceramic, glass, or rubber-lined steel.

The equipment used to mix the solution and inject it into the water is the same as that for liquid chlorine. Solutions of 1 or 2 percent available chlorine can be delivered by a diaphragm-type, chemical feed/metering pump.

Calcium hypochlorite is a corrosive material with a strong odor, and requires proper handling. It must be kept away from organic materials such as wood, cloth, and petroleum products. Reactions between calcium hypochlorite and organic material can generate enough heat to cause a fire or explosion.

Hypochlorination Equipment [13]

Hypochlorinators, used with chlorine in either liquid or solid form, pump or inject a chlorine solution into the water. When they are properly maintained, hypochlorinators provide a reliable method for applying chlorine to disinfect water.

Types of hypochlorinators include positive displacement feeders, aspirator feeds, suction feeders, and tablet hypochlorinators.

Positive displacement feeders. A common type of positive displacement hypochlorinator uses a piston or diaphragm pump to inject the solution. This type of equipment, which is adjustable during operation, can be designed to give reliable and accurate feed rates. When electricity is available, the stopping and starting of the hypochlorinator can be synchronized with the pumping unit. A hypochlorinator of this kind can be used with any water system; however, it is especially desirable in systems where water pressure is low and fluctuating.

Aspirator feeders. The aspirator feeder operates on a simple hydraulic principle that uses the vacuum created when water flows either through a venturi tube or perpendicular to a nozzle. The vacuum created draws the chlorine solution from a container into the chlorinator unit where it is mixed with water passing through the unit, and the solution is then injected into the water system. In most cases, the water inlet line to the chlorinator is connected to receive water from the discharge side of the water pump, with the chlorine solution being injected back into the suction side of the same pump. The chlorinator operates only when the pump is operating. Solution flow rate is regulated by means of a control valve, though pressure variations may cause changes in the feed rate.

Suction feeders. One type of suction feeder consists of a single line that runs from the chlorine solution container through the chlorinator unit and connects to the suction side of the pump. The chlorine solution is pulled from the container through suction created by the operating water pump.

Another type of suction feeder operates on the siphon principle, with the chlorine solution being introduced directly into a well. This type also consists of a single line, but the line terminates in the well below the water surface instead of the influent side of the water pump. When the pump is operating, the chlorinator is activated so that a valve is opened and the chlorine solution is passed into the well.

In each of these units, the solution flow rate is regulated by means of a control valve and the chlorinators operate only when the pump is operating. The pump circuit should be connected to a liquid level control so that the water supply pump operation is interrupted when the chlorine solution is exhausted.

Tablet hypochlorinators. The tablet hypochlorinating unit consists of a special pot feeder containing calcium hypochlorite tablets. Accurately controlled by means of a flow meter, small jets of feed water are injected into the lower portion of the tablet bed. The slow dissolution of the tablets provides a continuous source of fresh hypochlorite solution. The hypochlorinating unit controls the chlorine solution. This type of chlorinator is often used when electricity is not available, but requires adequate maintenance for efficient operation. It can operate where the water pressure is low.

Disinfection with Chlorine Gas

Chlorine is a toxic, yellow-green gas at standard temperatures and pressures. It is supplied as a liquid in high-strength, high-pressure steel cylinders, and immediately vaporizes when released. Small water systems can purchase the quantities they need from chemical or swimming pool suppliers.

Gas chlorinators used in small systems are often cylinder-mounted or wall-mounted systems. Figure 5-2 shows a gas chlorinator. Daily operation of a gas chlorinator consists of regulating the feed rate, starting and stopping the chlorinator, and changing the chlorine cylinders.

Chlorine gas, if accidentally released into the air, irritates the eyes, nasal membranes, and respiratory tract. It is lethal at concentrations as low as 0.1 percent air by volume. Therefore, systems using chlorine gas must have several major pieces of safety equipment:

- Chlorine gas detectors to provide early warning of leaks
- Self-contained breathing apparatus for the operator

[13] From U.S. Environmental Protection Agency, Office of Drinking Water, *Manual of Individual Water Supply Systems*, October 1982. EPA-570/9-82/004.

- A power ventilation system for rooms in which chlorine is housed
- Emergency repair kits

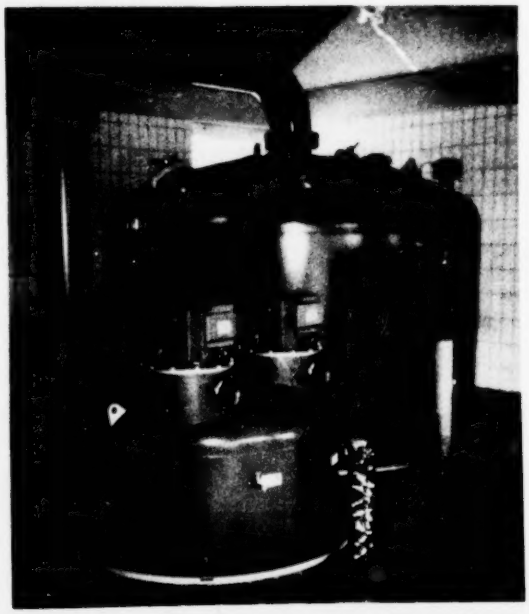
Chlorination Monitoring

Whenever chlorine is used for disinfection, the chlorine residual should be monitored at least daily. Samples should be taken at various locations throughout the water distribution system, including the farthest points of the system. Most small systems use a quick and simple test called the DPD colorimetric test, available as a kit from companies specializing in water-testing equipment and materials (Figure 5-3). Table 5-3 lists some companies that supply chlorine residual test kits. Appendix D describes how to take a sample for chlorine residual analysis.

Ozonation

Ozone (O_3) is widely used as a primary disinfectant in other parts of the world, but is relatively new to the United States as a drinking water disinfectant. A toxic gas formed when air containing oxygen flows between two electrodes, ozone is a powerful disinfectant, requiring shorter contact time than chlorine for disinfection.

Ozone gas is unstable and must be generated on site. In addition, it has a



Two-stage ozone system. (Courtesy of Carus Chemical Company)

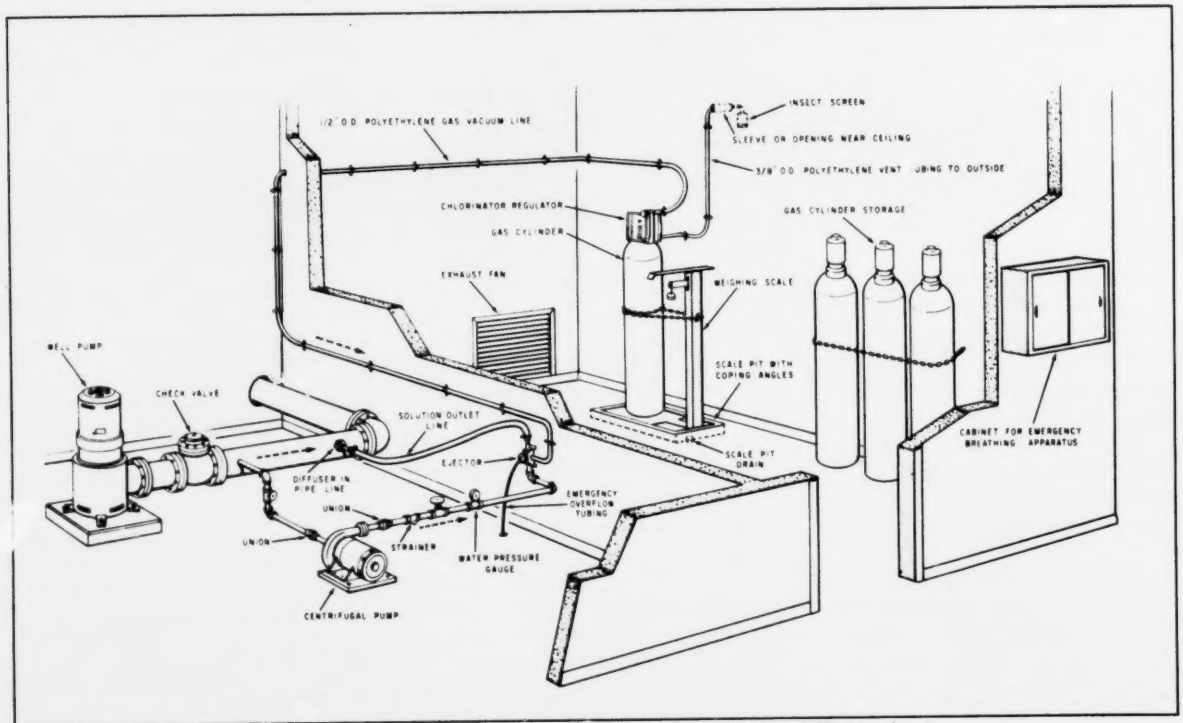


Figure 5-2. Typical deep well gas chlorination system. (Courtesy of Fischer & Porter, Inc.)

Table 5-3. Some Suppliers of Chlorine Residual Test Kits
Capital Controls Co. Box 211, Colmar, PA 18195 (215) 822-2901 (800) 523-2553
Fischer and Porter Co., County Line Rd., Warminster, PA 18974 (215) 674-6000 (800) 421-3411
Hach Co., Box 389, Loveland, CO 80537 (303) 669-3050 (800) 227-4224
Hydro Instruments, Inc., Box 615, Quakertown, PA (215) 538-1367
Wallace & Tiernan, 25 Main St., Belleville, NJ 07109 (201) 759-8000

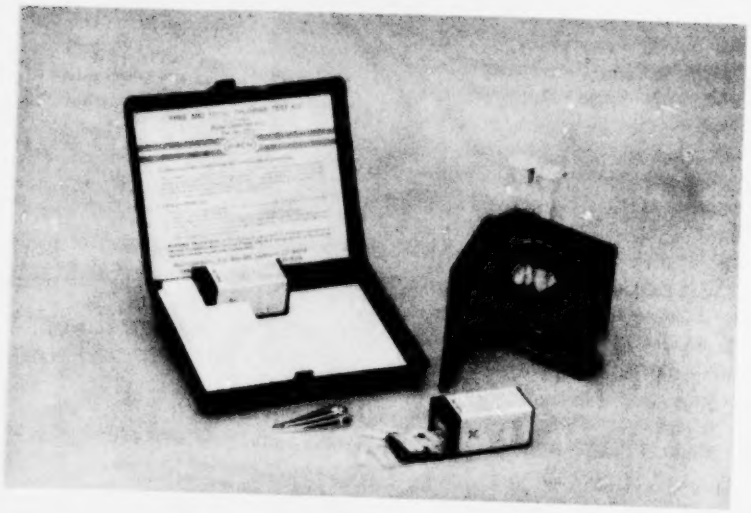


Figure 5-3. Test kit analyzes free and total chlorine. (Courtesy of Hach Company)

low solubility in water, so efficient contact with the water is essential. *A secondary disinfectant, usually chlorine, is required because ozone does not maintain an adequate residual in water.*

Pure oxygen or ambient (freely circulating) air can be used in ozone production. Pure oxygen delivers higher concentrations of ozone. Packaged ozone generator systems using oxygen to produce the ozone are available for small systems.

Air feed systems used for ozonation are classified by low, medium, or high operating pressure. (High pressure systems typically are used in small-to medium-sized applications.) These systems vary in their maintenance requirements, capital costs, and operating costs. The air feed systems are necessary to dry the air (lower its dew point) to increase the amount of ozone produced and to prevent fouling and corrosion of equipment.

Ozone used for water treatment is usually generated using a corona discharge cell consisting of two electrodes separated by a discharge gap and a dielectric plate (Figure 5-4). The dried air (or pure oxygen) flows between the electrodes and is converted to ozone. Several types of ozone generators are commercially available: horizontal tube, vertical tube, and plate generators. These systems are available with varying operating frequencies and voltages. An ozone contactor is used to dissolve the ozone in water. Ozone can be generated under positive or negative pressure, depending on the needs of the contactor to be used.

As with chlorine, the ozone demand of the water must be satisfied before an ozone residual is available for disinfection. This can be accomplished by using two ozone contacting chambers (Figure 5-5). The ozone delivered to the first chamber satisfies the ozone demand of the water, and the second chamber maintains the disinfecting residual.

Because ozone is toxic, the ozone in exhaust gases from the contactor must be recycled or removed and destroyed before venting. Figure 5-6 depicts a complete treatment system that includes ozone disinfection.

The capital costs of ozonation systems are relatively high and operation and maintenance are relatively complex. Electricity is a major part of operating costs, representing 26 to 43 percent of total operating and maintenance costs for small plants. Operation and maintenance for ozonation systems include periodic repair and replacement of equipment parts, periodic generator cleaning, annual maintenance of the contacting chambers, maintenance of the air preparation system, and day-to-day operation of the generating equipment (averaging 1/2 hour per day).

Monitoring the Ozonation System Operation

Proper monitors should be supplied with the ozonation system, including:

- Gas pressure and temperature monitors in the air preparation system
- Continuous monitors to determine moisture content of the dried gas fed to the ozone generator
- Generator coolant monitors
- Flow rate, temperature, and pressure monitors, and ozone concentration monitor for the gas discharged from the ozone generator to determine the ozone production rate
- Power input monitor for the ozone generator
- Ozone residual monitor

The ozone residual should be measured at a minimum of two points in the contactor(s). Ozone residual monitoring can be performed using a manual chemical analyzer (by a trained laboratory technician) or an in-line instrument that continuously samples the water.

Ultraviolet Radiation (UV)

Ultraviolet radiation effectively kills bacteria and viruses. As with ozone, *a secondary disinfectant must be used in addition to ultraviolet radiation to prevent regrowth of microorganisms in the water distribution system.* UV radiation can be attractive as a primary disinfectant for a small system because:

- It is readily available.
- It produces no known toxic residuals.
- Required contact times are short.
- The equipment is easy to operate and maintain.

Ultraviolet radiation, however, does not inactivate *Giardia* cysts, and cannot be used to treat water containing those organisms. Therefore, it is recommended only for ground water not directly influenced by surface water, in which there is no risk of *Giardia* cyst contamination. (Future ground-water disinfection rules will establish whether and how UV may be used.) UV radiation is unsuitable for water with high levels of suspended solids, turbidity, color, or soluble organic matter. These materials can react with or absorb the UV radiation, reducing the disinfection performance.

UV radiation is generated by a special lamp (Figure 5-7). When ultraviolet radiation penetrates the cell wall of an organism, it destroys the cell's genetic material and the cell dies.

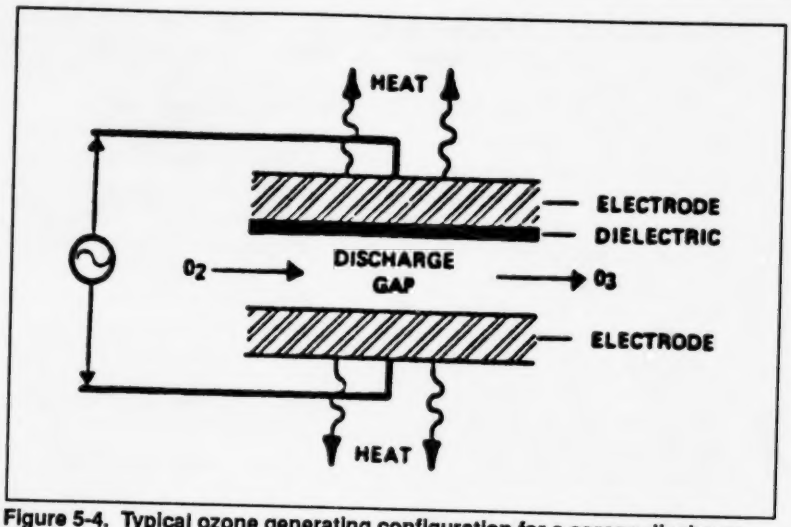


Figure 5-4. Typical ozone generating configuration for a corona discharge cell.

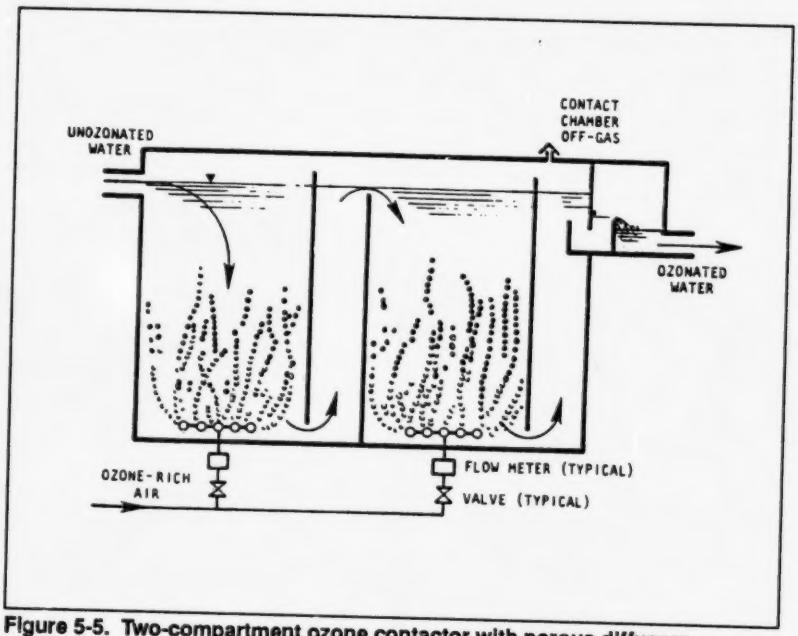


Figure 5-5. Two-compartment ozone contactor with porous diffusers.

The effectiveness of UV radiation disinfection depends on the energy dose absorbed by the organism, measured as the product of the lamp's intensity (the rate at which photons are delivered to the target) and the time of exposure. If the energy dosage is not high enough, the organism's genetic material might only be damaged instead of destroyed. To provide a safety factor, the dosage should be higher than needed to meet disinfection requirements. For example, if disinfection criteria require a 99.99 percent reduction of viruses, the UV system should be designed to provide a 99.999 percent reduction.

Substances in the raw water exert a UV demand similar to chlorine demand. The UV demand of the water affects the exposure time and intensity of the radiation needed for proper disinfection.

The most important operating factor for ultraviolet radiation disinfection is the cleanliness of surfaces through which the radiation must travel. Surface fouling can result in inadequate performance, so a strict maintenance schedule should be followed. Another important operating factor is the timely replacement of the UV lamps, because they lose their output intensity and this loss is not readily apparent. A sensor should be used at all times to ensure the desired dose.

Obtaining Effective Disinfection: CT Values

To ensure proper disinfection, the disinfectant must be in contact with the target organisms for a sufficient amount of time. *CT values* describe the degree of disinfection that can be obtained as a product of the disinfectant residual concentration, C, (in mg/L) and the contact time, T (in minutes). EPA's *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources* provides CT values for achieving various levels of inactivation of *Giardia* and viruses. Appendix E presents CT values for chlorine and ozone at several water temperatures and water pH levels for inactivating *Giardia* and viruses, and Appendix F provides an example of a CT calculation for a small system.

Disinfection By-Products and Strategies for Their Control

Adding a disinfectant to water might result in the production of harmful by-products.

Chlorine, for example, can mix with the natural organic compounds in water to form trihalomethanes (THMs).

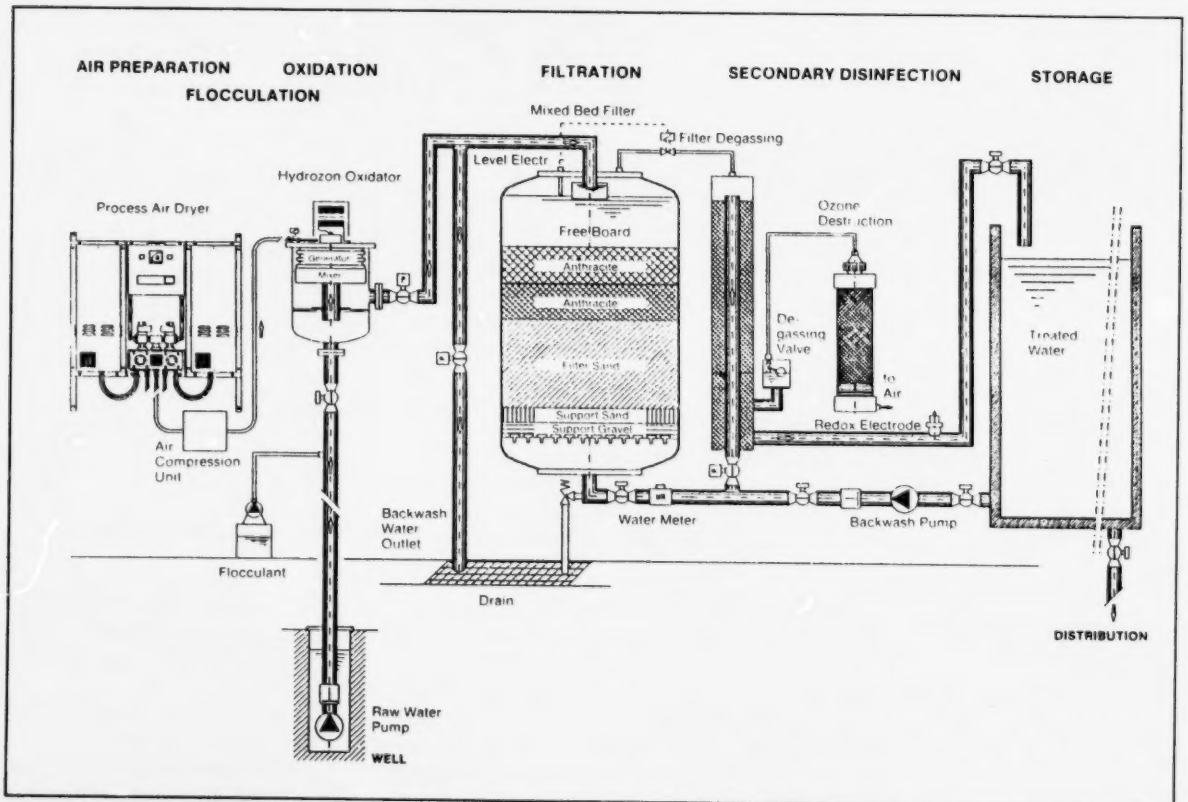


Figure 5-6. Schematic of system that provides primary disinfection with ozone, filtration, secondary disinfection, and excess ozone gas destruction. (Courtesy of Carus Chemical Company)

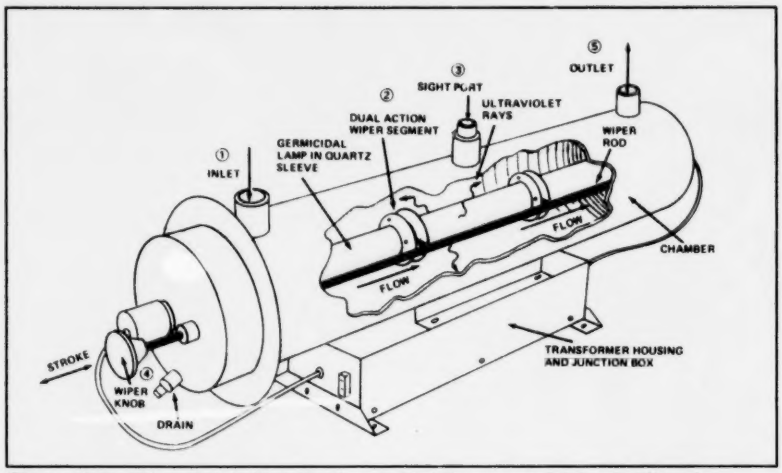


Figure 5-7. Ultraviolet disinfection unit. (Courtesy of Atlantic Ultraviolet Corporation)

One THM—chloroform—is a suspected carcinogen. Other common trihalomethanes are similar to chloroform and may cause cancer.

The formation of chlorination by-products depends on several factors, including:

- Temperature and pH of the water
- Chlorine dosage
- Concentration and types of organic materials in the water
- Contact time for free chlorine

Several strategies for minimizing harmful chlorination by-products can be used by small systems:

- **Reducing the concentration of organic materials before adding chlorine.** Common water clarification techniques, such as coagulation, sedimentation, and filtration, can effectively remove many organic materials. Activated carbon (described in Chapter 6) might be needed to remove organic materials at higher concentrations or those not removed by other techniques.
- **Reevaluating the amount of chlorine used.** The same degree of disinfection might be possible with lower chlorine dosages.
- **Changing the point in treatment where chlorine is added.** If chlorine is presently added before treatment (chemical feed, coagulation, sedimentation, and filtration), it can instead be added after filtration, or just before filtration and after chemical treatment.
- **Using alternative disinfection methods.** A system with a high concentration of chlorination by-products in the treated water might consider alternative disinfection methods. However, ozonation and ultraviolet radiation, the alternative methods most practical for small systems, cannot be used as disinfectants by themselves. Both require a secondary disinfectant (usually chlorine) to maintain a residual in the distribution system.

Ozonation might also result in the formation of some harmful by-products. Ozone can produce toxic by-products from a few synthetic organic compounds, such as the pesticide heptachlor. If ozone is added to water containing bromide ions, it can form brominated organic compounds such as bromine-containing trihalomethanes. Also, studies have shown that the addition of ozone followed by chlorine or chloramines can result in higher levels of certain by-products than when these disinfectants are used alone. For these reasons, it is important to know what compounds are in the raw water before choosing ozone as a disinfectant. Researchers are continuing to study ozonation by-products and their potential health effects.

Ultraviolet radiation might produce some by-products from organic compounds, but by-products of UV radiation have not yet been identified.

Chapter Six

Treating Organic Contaminants in Drinking Water

Some small drinking water systems face contamination of raw water by natural or synthetic organic substances. Sources of these substances include leaking underground gasoline/storage tanks, runoff of herbicides or pesticides, or improperly disposed of chemical wastes. Natural organic materials might also be present in water.

The technologies most suitable for organic contaminant removal in small systems are granular activated carbon (GAC) and aeration. Several emerging technologies using aeration may also be suitable for small systems.

Table 6-1 presents operational conditions for the organics treatment technologies most suitable for small systems. Table 6-2 presents removal effectiveness data for organic contaminants by granular activated carbon, packed column aeration, and diffused aeration. Information about organics removal effectiveness is not yet available for the other technologies described in this chapter.

Granular Activated Carbon (GAC)

Granular activated carbon (GAC) removes many organic contaminants from water supplies. Congress has designated GAC as the Best Available Technology (BAT) for synthetic organic chemical removal.

Activated carbon is carbon that has been exposed to very high temperature, creating a vast network of internal pores (Figure 6-1). It removes contaminants through adsorption, a process in which dissolved contaminants adhere to the porous surface of the carbon particles. Because activated carbon is very porous, it has a large internal surface area; 1 gram of activated carbon has a surface area equivalent to a football field. One

Table 6-1. Operational Conditions for Organic Treatments

Technology	Level of Operational Skill Required	Level of Maintenance Required	Energy Requirements
Granular activated carbon (GAC)	Medium	Low	Low
Packed column aeration (PCA)	Low	Low	Varies
Diffused aeration	Low	Low	Varies
Multiple tray aeration	Low	Low	Low
Mechanical aeration	Low	Low	Low
Catenary grid	Low	Low	High
Higee aeration	Low	Medium	High

Source: U.S. Environmental Protection Agency, Office of Drinking Water and Center for Environmental Research Information, *Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities,* March 1990. EPA 625/4-89-023.

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Table 6-2. Treatment Technology Removal Effectiveness Reported for Organic Contaminants (Percent)[a]

Contaminant	Granular Activated Carbon (GAC)	Packed Column Aeration (PCA)	Diffused Aeration
Acrylamide	NA	1-29	NA
Alachlor	0-49	70-100	NA
Aldicarb	NA	0-29	NA
Benzene	70-100	70-100	NA
Carbofuran	70-100	0-29	11-20
Carbon tetrachloride	70-100	70-100	NA
Chlordane	70-100	0-29	NA
Chlorobenzene	70-100	70-100	NA
2,4-D	70-100	70-100	NA
1,2-Dichloroethane	70-100	70-100	42-77
1,2-Dichloropropane	70-100	70-100	12-79
Dibromochloropropane	70-100	30-69	NA
Dichlorobenzene	70-100	NA	NA
o-Dichlorobenzene	70-100	70-100	14-72
p-Dichlorobenzene	70-100	70-100	NA
1,1-Dichloroethylene	70-100	70-100	97
cis-1,2-Dichloroethylene	70-100	70-100	32-85
trans-1,2-Dichloroethylene	70-100	70-100	37-96
Epichlorohydrin	NA	0-29	NA
Ethylbenzene	70-100	70-100	24-89
Ethylene dibromide	70-100	70-100	NA
Heptachlor	70-100	70-100	NA
Heptachlor epoxide	NA	NA	NA
High molecular weight hydrocarbons (gasoline, dyes, amines, humics)	W	NA	NA
Lindane	70-100	0-29	NA
Methoxychlor	70-100	NA	NA
Monochlorobenzene	NA	NA	14-85
Natural organic material	P	NA	NA
PCBs	70-100	70-100	NA
Phenol and chlorophenols	W	NA	NA
Pentachlorophenol	70-100	0	NA
Styrene	NA	NA	NA
Tetrachloroethylene	70-100	NA	73-95
Trichloroethylene	70-100	70-100	53-95
Tricholoroethane	70-100	NA	NA
1,1,1-Trichloroethane	70-100	70-100	58-90
Toluene	70-100	70-100	22-89
2,4,5-TP	70-100	NA	NA
Toxaphene	70-100	70-100	NA
Vinyl chloride	70-100	70-100	NA
Xylenes	70-100	70-100	18-89

[a]Additional treatment information is available in EPA Office of Drinking Water Health Advisories for specific contaminants.

W = well removed. P = poorly removed. NA = not available.

Note: Little or no specific performance data were available for:
1. Multiple Tray Aeration
2. Catenary Aeration
3. Higee Aeration
4. Mechanical Aeration

Source: U.S. Environmental Protection Agency, Office of Drinking Water and Center for Environmental Research Information, *Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities*, March 1990. EPA 625/4-89-023.

pound of activated carbon can adsorb over 1/2 pound of carbon tetrachloride.

GAC has an affinity for high molecular weight compounds. It is not effective in removing vinyl chloride, a highly volatile substance, from water. Table 6-3 lists organics that are readily or poorly adsorbed by activated carbon.

GAC can be used as a replacement for existing media (such as sand) in a conventional filter or it can be used in a separate contactor (a vertical steel pressure vessel used to hold the activated carbon bed).

GAC contactors require monitoring to ensure that they work effectively. A GAC monitoring system should include:

- Laboratory analysis of treated water to ensure that the system is removing organic contaminants
- Monitoring of headloss (the amount of energy used by water in moving from one point to another) through the contactors to ensure that backflushing (reversing the flow to remove trapped material) is performed at appropriate times
- Bacteria monitoring of the contactor's effluent (since bacteria can grow rapidly within the activated carbon bed)
- Turbidity monitoring of the contactor's effluent (to determine if suspended material is passing through GAC bed)

After a period of a few months or a few years, depending on the concentration of contaminants, the surface of the pores in the GAC can no longer adsorb contaminants. The carbon must then be replaced.

Several operational and maintenance factors affect the performance of GAC. Contaminants in the water can occupy GAC adsorption sites, whether they are targeted for removal or not. Also, adsorbed contaminants can be replaced by other contaminants with

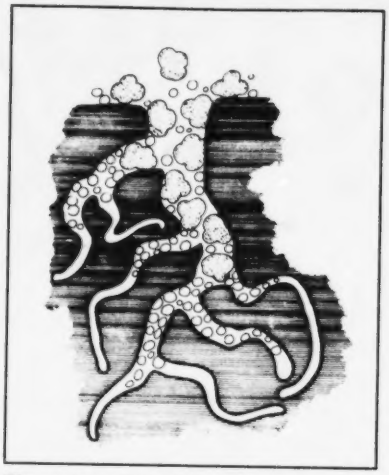

Figure 6-1. Representation of internal carbon structure. (Reprinted from *Introduction to Water Treatment,* Vol. 2, by permission. Copyright 1984, American Water Works Association.)

which GAC has a greater affinity. Therefore, the presence of other contaminants might interfere with the removal of the contaminants of concern.

A significant drop in the contaminant level in influent water will cause a GAC filter to desorb, or slough off, adsorbed contaminants, because GAC is an equilibrium process. As a result, raw water with frequently changing contaminant levels can result in treated water of unpredictable quality.

Bacterial growth on the carbon is another potential problem. Excessive bacterial growth may cause clogging and higher bacterial counts in the treated water. This means that bacterial levels in the treated water must be closely monitored and the final disinfection process must be carefully controlled.

GAC is available in different grades of effectiveness. Low-cost carbon requires a lower initial capital outlay, but must be replaced more often, resulting in higher operating costs.

Aeration

Aeration, also known as air stripping, mixes air with water to volatilize

Table 6-3. Readily and Poorly Adsorbed Organics

Readily Adsorbed Organics

- Aromatic solvents (benzene, toluene, nitrobenzenes)
- Chlorinated aromatics (PCBs, chlorobenzenes, chloronaphthalene)
- Phenol and chlorophenols
- Polynuclear aromatics (acenapthene, benzopyrenes)
- Pesticides and herbicides (DDT, aldrin, chlordane, heptachlor)
- Chlorinated aliphatics (carbon tetrachloride, chloroalkyl ethers)
- High molecular weight hydrocarbons (dyes, gasoline, amines, humics)

Poorly Adsorbed Organics

- Alcohols
- Low molecular weight ketones, acids, and aldehydes
- Sugars and starches
- Very high molecular weight or colloidal organics
- Low molecular weight aliphatics

Source: U.S. Environmental Protection Agency, Office of Drinking Water and Center for Environmental Research Information, *Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities,* March 1990. EPA 625/4-89-023.

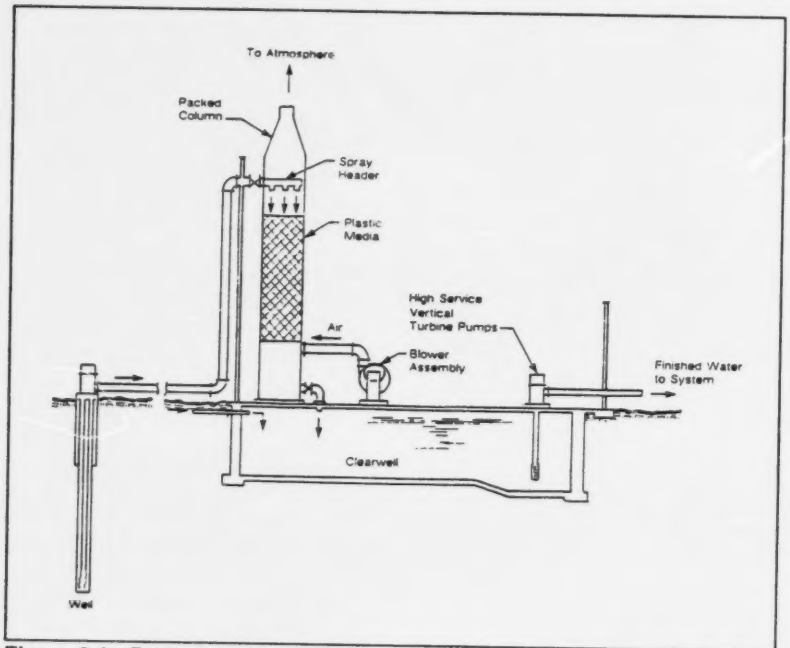

Figure 6-2. Packed tower aeration system.

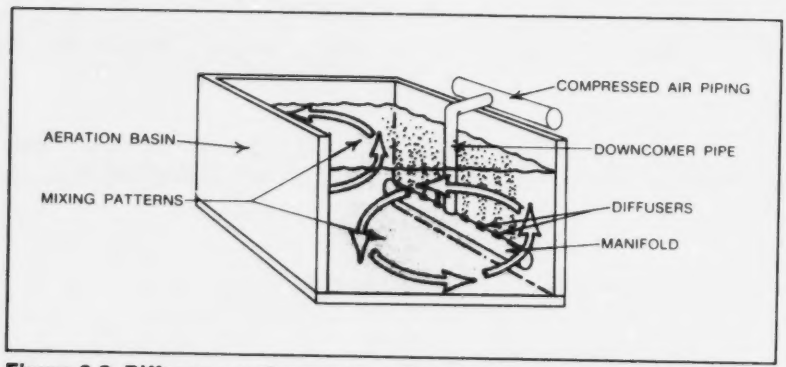

Figure 6-3. Diffuser aeration system. (Reprinted from *Introduction to Water Treatment*, Vol. 2, by permission. Copyright 1984, American Water Works Association.)

Aeration, also known as air stripping, mixes air with water to volatilize contaminants (turn them to vapor). The volatilized contaminants are either released directly to the atmosphere or are treated and then released. Aeration is used to remove volatile organic chemicals and can also remove radon (see Chapter 7).

A small system might be able to use a simple aerator constructed from relatively common materials instead of a specially designed aerator system. Examples of simple aerators include:

- A system that cascades the water or passes it through a slotted container
- A system that runs water over a corrugated surface
- An airlift pump that introduces oxygen as water is drawn from a well

Other aeration systems that might be suitable for small systems include packed column aeration, diffused aeration, and multiple tray aeration. Emerging technologies that use aeration for organics removal include mechanical aeration, catenary grid, and Higee aeration.

Packed Column Aeration

Packed column aeration (PCA) or packed tower aeration (PTA) is a waterfall aeration process which drops water over a medium within a tower to mix the water with air. The medium is designed to break the water into tiny droplets, and maximize its contact with tiny air bubbles for removal of the contaminant. Air is also blown in from underneath the medium to enhance this process. Figure 6-2 shows a PCA system.

Systems using PCA may need pretreatment to remove iron, solids, and biological growth to prevent clogging of the packing material. Posttreatment (such as the use of a corrosion inhibitor) may also be needed to reduce corrosive properties in water due to increased dissolved oxygen from the aeration process.

Packed columns usually operate automatically, and need only daily visits to ensure that the equipment is running satisfactorily. Maintenance requirements include servicing pump and blower motors and replacing air filters on the blower, if necessary.

PCA exhaust gas may require treatment to meet air emissions regulations, which can significantly increase the costs of this technology.

Diffused Aeration

In a diffused aeration system, a diffuser bubbles air through a contact chamber for aeration (Figure 6-3). The main advantage of diffused aeration systems is that they can be created from existing structures, such as storage tanks. However, they are less effective than packed column aeration, and usually are used only in systems with adaptable existing structures.

Multiple Tray Aeration

Multiple tray aeration directs water through a series of trays made of slats, perforations, or wire mesh (Figure 6-4). A blower introduces air from underneath the trays.

Multiple tray aeration units have less surface area than do PCA units. This type of aeration is not as effective as PCA, and can experience clogging from iron and manganese, biological growth, and corrosion problems. Multiple tray aeration units are readily available from package plant manufacturers.

Emerging Technologies for Organics Removal

Mechanical Aeration

Mechanical aeration uses mechanical stirring mechanisms to mix air with the water (Figure 6-5). These systems can effectively remove volatile organic chemicals (VOCs).

Mechanical aeration units need large amounts of space because they demand long detention times for effective treatment. As a result, they often require open-air designs, which can freeze in cold climates. These units also can have high energy requirements. However, mechanical aeration systems are easy to operate, and are less susceptible to clogging from biological growth than PCA systems.

Catenary Grid

Catenary grid systems are a variation of the packed column aeration process. The catenary grid directs water through a series of wire screens mounted within the column. The screens mix the air and water in the same way as packing materials in PCA systems. Figure 6-6 shows a catenary grid unit.

These systems can effectively remove volatile organic chemicals. There is little information available about the effectiveness of catenary grid systems for other organic compounds, but they probably would not remove these compounds effectively. They have higher energy requirements than PCA systems, but their more compact design lowers their capital cost relative to PCA.

Higee Aeration

Higee aeration is another variation of the PCA process. These systems pump water into the center of a spinning disc of packing material, where the water mixes with air (Figure 6-7).

Higee units require less packing material than PCA units to achieve the same removal efficiencies. Because of their compact size, they can be used in limited spaces and heights. Current Higee systems are best suited for temporary applications of less than 1 year with capacities up to 380 liters (100 gallons) per minute.

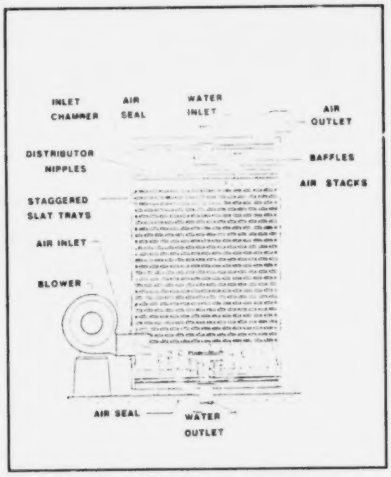

Figure 6-4. Schematic of a redwood slat tray aerator

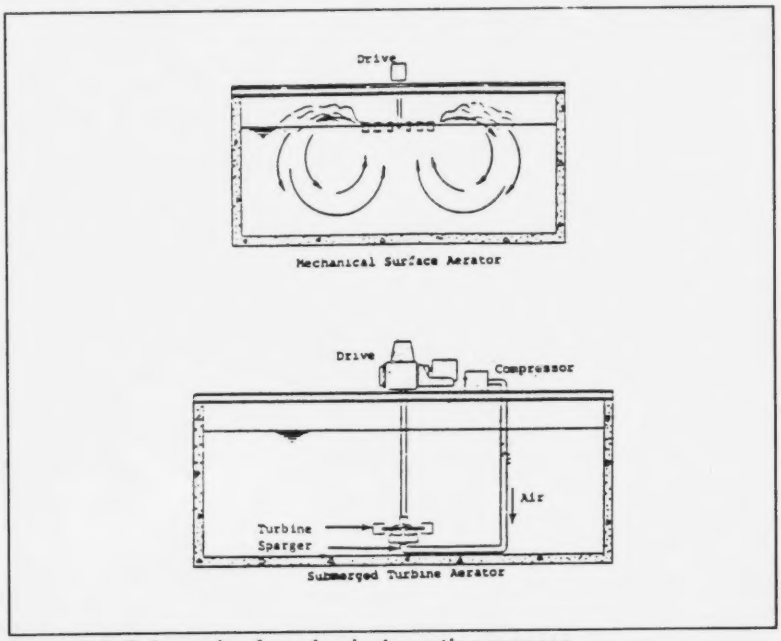

Figure 6-5. Schematic of mechanical aeration process.

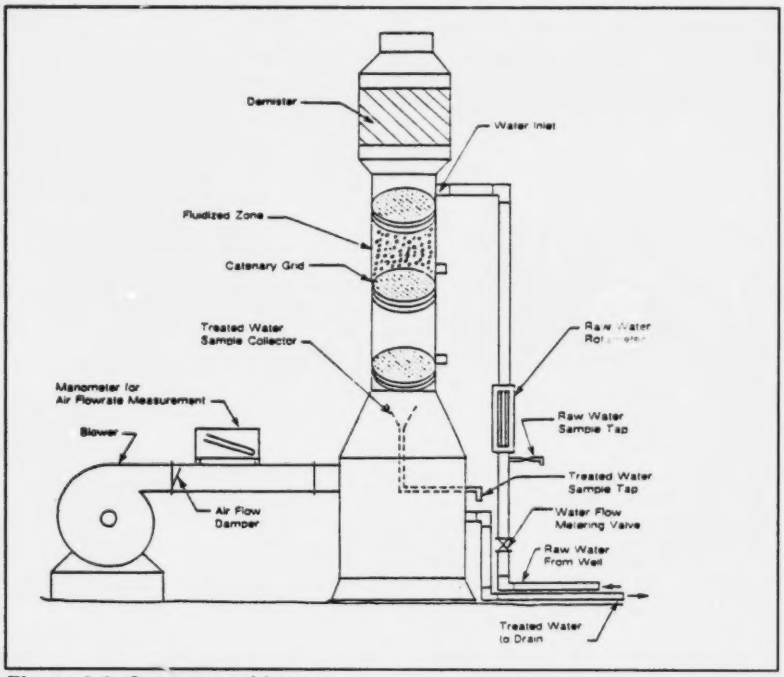

Figure 6-6. Catenary grid system.

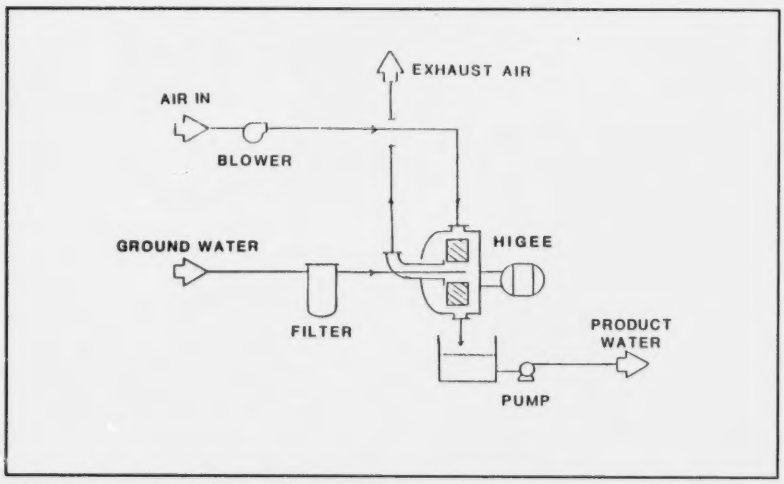

Figure 6-7. Schematic of Higee system.

Chapter Seven

Control and Removal of Inorganic Contaminants

Water systems control or remove inorganic contaminants using two different strategies:

1. **Preventing inorganic contamination of finished water.** Corrosion controls prevent or minimize the presence of corrosion products (such as lead and copper) at the consumer's tap.

2. **Removing inorganic contaminants from raw water.** Removal technologies treat source water that is contaminated with metals or radioactive substances (radionuclides).

Inorganic contaminants presently regulated under the Safe Drinking Water Act (SDWA) include lead, radium, nitrate, arsenic, selenium, barium, fluoride, cadmium, chromium, mercury, and silver.

This chapter describes several technologies for inorganic contaminant removal (reverse osmosis, ion exchange, activated alumina, aeration, and granular activated carbon). Conventional treatment (coagulation/filtration) can also remove inorganic contaminants and is discussed in this chapter.

Corrosion

Corrosion is the deterioration of a substance by chemical action. Lead, cadmium, zinc, copper, and iron might be found in water when metals in water distribution systems corrode. Drinking water contaminated with certain metals (such as lead and cadmium) can harm human health.

Corrosion also reduces the useful life of water distribution systems, and can promote microorganism growth, resulting in disagreeable tastes, odors, slimes, and further corrosion. Often a customer complaint is the first indication of a corrosion problem, and at this stage corrosion may be extensive.

Table 7-1 shows typical customer complaints and their causes.

Controlling Lead Levels in Drinking Water

Because it is widespread and highly toxic, lead is the corrosion product of greatest concern. Table 7-2 shows the risk factors that can indicate potentially high lead levels at the tap. Lead levels in drinking water are managed indirectly through corrosion controls. Lead is not typically found in source water, but rather at the consumer's tap as a result of the corrosion of the plumbing or distribution system. The 1986 amendments to the Safe Drinking Water Act ban the use of lead solders, fluxes, and pipes in the installation or repair of any public water system or in any plumbing system providing water for human consumption. In the past, solder used in plumbing has been 50 percent tin and 50 percent lead. Using lead-free solders, such as silver-tin and antimony-tin solders is a key factor in lead corrosion control. Replacement of lead pipes can also be an effective strategy for reducing lead in drinking water.

The current Maximum Contaminant Level (MCL) for lead applies to water delivered by the supplier. New lead regulations might include an MCL for water at the consumer's tap.

If tests for corrosion by-products find unacceptably high levels of lead, immediate steps should be taken to minimize consumers' exposure until a long-term corrosion control plan is implemented. Some short-term measures the consumer can take include:

- Running the water for about 1 minute before each use
- Using home treatment processes in extreme cases
- Using bottled water

Table 7-1. Typical Customer Water Quality Complaints That Might Be Due to Corrosion

Customer Complaint	Possible Cause
Red water or reddish-brown staining of fixtures and laundry	Corrosion of iron pipes or presence of natural iron in raw water
Bluish stains on fixtures	Corrosion of copper lines
Black water	Sulfide corrosion of copper or iron lines or precipitations of natural manganese
Foul taste and/or odors	By-products from microbial activity
Loss of pressure	Excessive scaling, tubercle buildup from pitting corrosion, leak in system from pitting or other type of corrosion
Lack of hot water	Buildup of mineral deposits in hot water system (can be reduced by setting thermostats to under 60°C [140°F])
Short service life of household plumbing	Rapid deterioration of pipes from pitting or other types of corrosion

Source: U.S. Environmental Protection Agency, Office of Drinking Water, *Corrosion Manual for Internal Corrosion of Water Distribution Systems,* April 1984. EPA 570/9-84-001.

Table 7-2. Risk Factors Indicating Potentially High Lead Levels at the Tap

- Components of the water distribution system or structure's plumbing are made of lead, or lead-containing material such as brass, and/or the structure's plumbing has solder containing lead.

And one or more of the following apply:

- The structure is less than 5 years old.
- The tap water is soft and/or acidic.
- The water stays in the plumbing for 6 or more hours.
- The structure's electrical system is grounded to the plumbing system.

Source: Adapted from U.S. Environmental Protection Agency, Office of Drinking Water and Center for Environmental Research Information, *Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities,* March 1990. EPA 625/4-89-023.

Techniques for Controlling Corrosion

Solutions to corrosion problems include modifying the water quality (especially pH and alkalinity), and adding corrosion inhibitors to form protective coatings over metal. It should also be noted that corrosion in a homeowner's plumbing can be related to conditions in the home (such as pipes that are too small or the use of dissimilar metals in joining pipes and valves) rather than to the quality of water from the distribution system.

Modifying water quality. Table 7-3 shows some of the characteristics of water that affect its corrosivity. All water is corrosive to some degree, but water that is acidic (less than 7.0 pH) is likely to corrode metal more quickly.

Table 7-3. Chemical Factors Influencing Corrosion and Corrosion Control

Factor	Effect
pH	Low pH may increase corrosion rate; high pH may protect pipes and decrease corrosion rates
Alkalinity	May help form protective calcium carbonate ($CaCO_3$) coating, helps control pH changes, reduces corrosion
Dissolved oxygen (DO)	Increases rate of many corrosion reactions
Chlorine residual	Increases metallic corrosion
Total dissolved solids (TDS)	High TDS increases conductivity and corrosion rate
Hardness (Ca and Mg)	Ca may precipitate as $CaCO_3$ and thus provide protection and reduce corrosion rates
Chloride, sulfate	High levels increase corrosion of iron, copper, and galvanized steel
Hydrogen sulfide	Increases corrosion rates
Silicate, phosphates	May form protective films
Natural color, organic matter	May decrease corrosion
Iron, zinc, or manganese	May react with compounds on interior of asbestos-cement pipe to form protective coating

Source: U.S. Environmental Protection Agency, Office of Drinking Water, *Corrosion Manual for Internal Corrosion of Water Distribution Systems,* April 1984. EPA 570/9-84-001.

Adjusting pH and alkalinity is the most common corrosion control method, because it is simple and inexpensive. (pH is a measure of the concentration of hydrogen ions present in water; alkalinity is a measure of water's ability to neutralize acids.) Generally, an increase in pH and alkalinity can decrease corrosion rates and help form a protective layer of scale on corrodible pipe material. Chemicals commonly used for pH and alkalinity adjustment are lime, caustic soda, soda ash, and sodium bicarbonate. Adjusting pH to control corrosion, however, might conflict with ideal pH conditions for disinfection and control of disinfection by-products. Drinking water suppliers should carefully choose the treatment methods so that both disinfection and corrosion control are effective.

Avoiding high dissolved oxygen levels decreases water's corrosive activity. Removing oxygen from water is not practical because of cost. However, treatment systems might be able to minimize the dissolved oxygen levels by minimizing air/water contact.

Corrosion inhibitors. Corrosion inhibitors reduce corrosion by forming protective coatings on pipes. The most common corrosion inhibitors are inorganic phosphates, sodium silicates, and mixtures of phosphates and silicates. These chemicals have proven successful in reducing corrosion in many systems.

Treatment Technologies for Removing Inorganic Contaminants

Inorganic contamination of raw water supplies can come from a wide variety of sources. Naturally occurring inorganics, such as fluoride, arsenic, selenium, and radium, are commonly found in ground-water sources. Synthetic contaminants are usually found in surface water supplies. Nitrates and nitrites are a problem in agricultural areas and areas without sanitary sewer systems, and have been found at relatively high levels in both surface water and ground water.

No single treatment is perfectly suited for all inorganic contaminants. Table 7-4 shows the removal effectiveness of six inorganic treatment processes

Table 7-4. Most Probable Applications of Water Treatment Processes for Inorganic Contaminant Removal

Treatment Process	Principal Application for Water Treatment	Inorganic Contaminant Treatment Capability Effectivenessa			Most Probable Application for Inorganic Removal
		High	Moderate	Low	
Conventional coagulation	Clarification of surface waters	Cd Cr III Cr VI As V Ag Pb	As III Se IV Hg (O) Hg (I)	Ba F No_3 Ra Se VI	Removal of Cd, Cr, As, Ag, or Pb from surface waters
Cation exchange	Removal of hardness from ground water	Ba Ra Cd Pb Cr III		As Se NO_3 F Cr VI	Removal of Ba or Ra from ground water
Anion exchange	Removal of nitrate from ground water	NO_3 Cr VI Se		Ba Ra Cd Pb Cr III	Removal of NO_3 from ground water
Activated alumina	Removal of fluoride from ground water	F As Se		Ba Ra Cd	Removal of F, As, or Se from ground water
Granular activated carbon	Removal of taste, odors, and organics	Hg(I) Hg(O)	Cd	Ag Ba Ra Cr III F NO_3	Removal of Hg from surface or ground water
Reverse osmosis and electrodialysis	Desalting of sea water or brackish ground water	As V Ba Cr Pb Cd Se Ag F Ra Hg	NO_3 As III		Removal of all inorganics from ground water

[a]High—greater than 80 percent; moderate—20 to 80 percent; low—less than 20 percent.

Ag = Silver
As = Arsenic
Ba = Barium
Cd = Cadmium
Cr = Chromium
F = Fluoride
Hg = Mercury
NO_3 = Nitrate
Pb = Lead
Ra = Radium
Se = Selenium

Source: Adapted from Thomas J. Sorg and Gary S. Logsdon, "Treatment Technology to Meet the Interim Primary Drinking Water Regulations for Inorganics: Part 5," *Journal of the American Water Works Association*, July 1980.

and their most probable application for inorganic removal. Processes suitable for small systems include:

- Coagulation/filtration
- Membranes (reverse osmosis and electrodialysis)
- Ion exchange
- Activated alumina

Table 7-5 presents advantages and disadvantages of these processes. Coagulation/filtration is generally too operationally complex for very small systems (serving 500 people or fewer). Reverse osmosis, ion exchange, and activated alumina are simpler operations and may be better alternatives for these systems, unless the contaminant of concern cannot be removed by these processes, or unless the costs or maintenance requirements are prohibitive. Each of these processes is described below. Aeration and granular activated carbon, commonly used to remove radon from water supplies, are also discussed below.

Coagulation/Filtration

Coagulation (described in Chapter 4) is traditionally used to control turbidity, hardness, taste, and odors, but is also effective in removing some inorganic contaminants.

Coagulation using aluminum or iron salts is effective in removing most metal ions or colloidally dispersed compounds (finely divided substances that do not settle out of water for a very long period of time). It is ineffective in removing nitrate, nitrite, radium, and barium. Table 7-6 presents potential removal efficiencies using aluminum and iron salts as coagulants. Coagulation to remove inorganics is more expensive than coagulation to remove turbidity because higher dosages of coagulant are needed.

Table 7-5. Advantages and Disadvantages of Inorganic Contaminant Removal Processes

Coagulation/Filtration

Advantages

- Low cost for high volume
- Reliable process well suited to automatic control

Disadvantages

- Not readily applied to small or intermittent flows
- High-water-content sludge disposal
- Very low contaminant levels may require two-stage precipitation
- Requires highly trained operators

Membranes (Reverse Osmosis and Electrodialysis)

Advantages

- Removes nearly all contaminant ions and most dissolved non-ions
- Relatively insensitive to flow and total dissolved solids level
- Low effluent concentration possible
- In reverse osmosis, bacteria and particles are also removed
- Automation allows for less operator attention

Disadvantages

- High capital and operating costs
- High level of pretreatment required in some cases
- Membranes are prone to fouling (RO). Electrodes require replacement (ED).

Ion Exchange

Advantages

- Relatively insensitive to flow variations
- Essentially zero level of effluent contamination possible
- Large variety of specific resins available

Disadvantages

- Potential for unacceptable levels (peaks) of contamination in effluent
- Waste requires careful disposal
- Usually not feasible at high levels of total dissolved solids
- Pretreatment required for most surface waters

Activated Alumina

Advantages

- Insensitive to flow and total dissolved solids background
- Low effluent contaminant level possible
- Highly selective for fluoride and arsenic

Disadvantages

- Strong acid and base are required for regeneration
- Medium tends to dissolve, producing fine particles
- Adsorption is slow
- Waste requires careful disposal

Source: U.S. Environmental Protection Agency, Office of Drinking Water and Center for Environmental Research Information, *Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities*, March 1990. EPA 625/4-89-023.

Table 7-6. Removal Efficiency Potential of Alum Versus Ferric Chloride

Inorganic Contaminant	Removal Efficiency: Alum Coagulant	Removal Efficiency: Iron Coagulant
Ag (pH < 8.0)	90%	-
Ag (pH = 8.0)	-	70%
As V	-	90%
As V (pH < 7.5)	90%	-
As V (pH = 7.5)	-	90%
Cd (pH ≥ 8.0)	-	-
Cd (pH ≥ 8.5)	70%	-
Cr (III)	90%	-
Cr III (pH = 10.5)	-	90%
Cr VI (using Fe II)	-	90%
Hg	70%	-
Pb	90%	-

Ag = Silver
As = Arsenic
Cd = Cadmium
Cr = Chromium
Hg = Mercury
Pb = Lead

Source: U.S. Environmental Protection Agency, Office of Drinking Water and Center for Environmental Research Information, *Technologies for Upgrading Existing or Designing New Drinking Water Treatment Facilities*, March 1990. EPA 625/4-89-023.

Reverse Osmosis and Electrodialysis

Reverse osmosis removes contaminants from water using a semipermeable membrane that permits only water, and not dissolved ions (such as sodium and chloride), to pass through its pores (Figure 7-1). Contaminated water is subjected to a high pressure that forces pure water through the membrane, leaving contaminants behind in a brine solution. Membranes are available with a variety of pore sizes and characteristics.

Reverse osmosis can effectively remove nearly all inorganic contaminants from water. It removes over 70 percent of arsenic(III), arsenic(IV), barium, cadmium, chromium(III), chromium(VI), fluoride, lead, mercury, nitrite, selenium(IV), selenium(VI), and silver. Properly operated units will attain 96 percent removal rates. Reverse osmosis can also effectively remove radium, natural organic substances, pesticides, and microbiological contaminants.

Reverse osmosis systems are compact, simple to operate, and have minimal labor requirements, making them suitable for small systems. They are also suitable for systems with a high degree of seasonal fluctuation in water demand.

One disadvantage of reverse osmosis is its high capital and operating costs. For systems of less than 3.8 million liters per day (1 million gallons per day [MGD]), operating costs range from $3 to $6 per 3,800 liters (thousand gallons) of treated water. Capital costs range from $1 to $2 per 3.8 liters (gallon) of capacity, depending on the level of pretreatment required. Managing the wastewater (brine solution) is also a potential problem for systems using reverse osmosis.

Electrodialysis is a process that also uses membranes. In this process, however, direct electrical current is used to attract ions to one side of the treatment chamber. Electrodialysis systems include a source of pressurized water, a direct current power supply, and a pair of selective membranes. Multistage units, in which membrane pairs are "stacked" in the treatment vessel, can increase the removal efficiency. Electrodialysis is very effective in removing fluoride and nitrate, and can also remove barium, cadmium, and selenium.

Ion Exchange

Ion exchange units (Figure 7-2) can be used to remove any ionic (charged) substance from water, but are usually used to remove hardness and nitrate from ground water. Inorganic substances are removed by adsorption onto an exchange medium, usually a synthetic resin. One ion is exchanged for another on the surface of the medium, which is regenerated with the exchangeable ion before treatment operations. Ion exchange waste is highly concentrated and requires careful disposal.

The ion exchange process, like reverse osmosis, can be used with fluctuating flow rates. Pretreatment

with filtration might be needed if the influent has a high level of suspended solids. Ion exchange units are also sensitive to the presence of competing ions. For example, influent with high levels of hardness will compete with other cations (positive ions) for space on the exchange medium, and the exchange medium must be regenerated more frequently.

Ion exchangers often use sodium chloride to regenerate the exchange medium because of the chemical's low cost. However, this might result in a high sodium residual in the finished water. High sodium residual might be unacceptable for individuals with salt-restricted diets. This problem can be avoided by using other regenerant materials, such as potassium chloride.

Ion exchange effectively removes more than 90 percent of barium, cadmium, chromium (III), silver, radium, nitrites, selenium, arsenic (V), chromium (VI), and nitrate. Ion exchange is usually the best choice for small systems to remove radionuclides.

Activated Alumina

Activated alumina systems are illustrated in Figure 7-3. Activated alumina is a commercially available ion exchange medium, primarily used to remove fluoride from ground water. The activated alumina medium is regenerated using a strong sodium hydroxide solution. Because this increases the pH level of the water, sulfuric acid must be added to the water after it leaves the exchange unit.

Activated alumina removes over 90 percent of arsenic (V), fluoride, and selenium (IV), and 70 percent of selenium (VI). It also effectively removes iron. It is not effective in removing barium, cadmium, and radium.

While activated alumina effectively removes several contaminants, it can be hazardous because of the strongly acidic and basic solutions used. Another disadvantage of activated

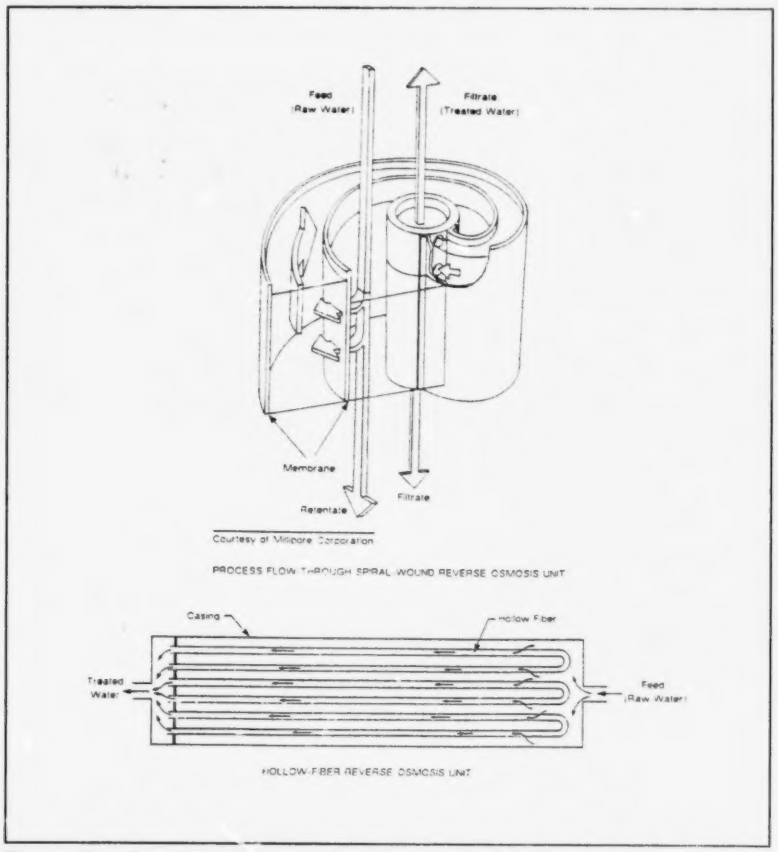

Figure 7-1. Two types of reverse osmosis membranes.

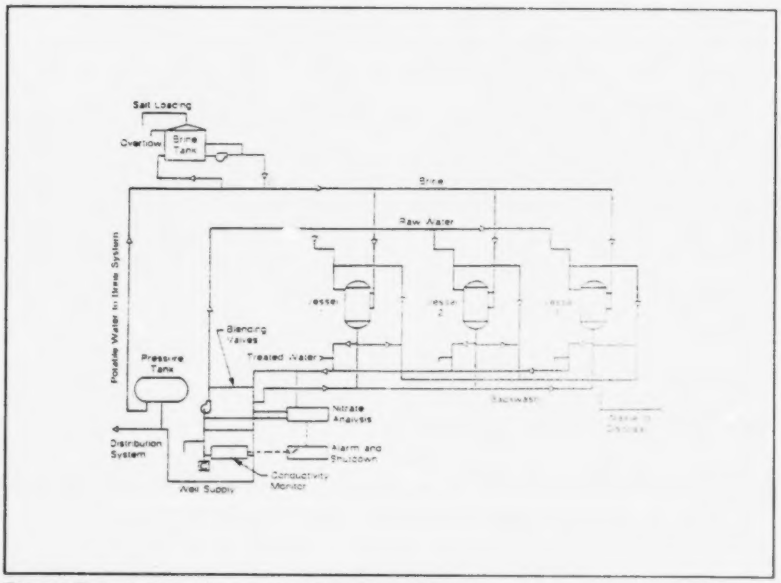

Figure 7-2. Ion exchange treatment system.

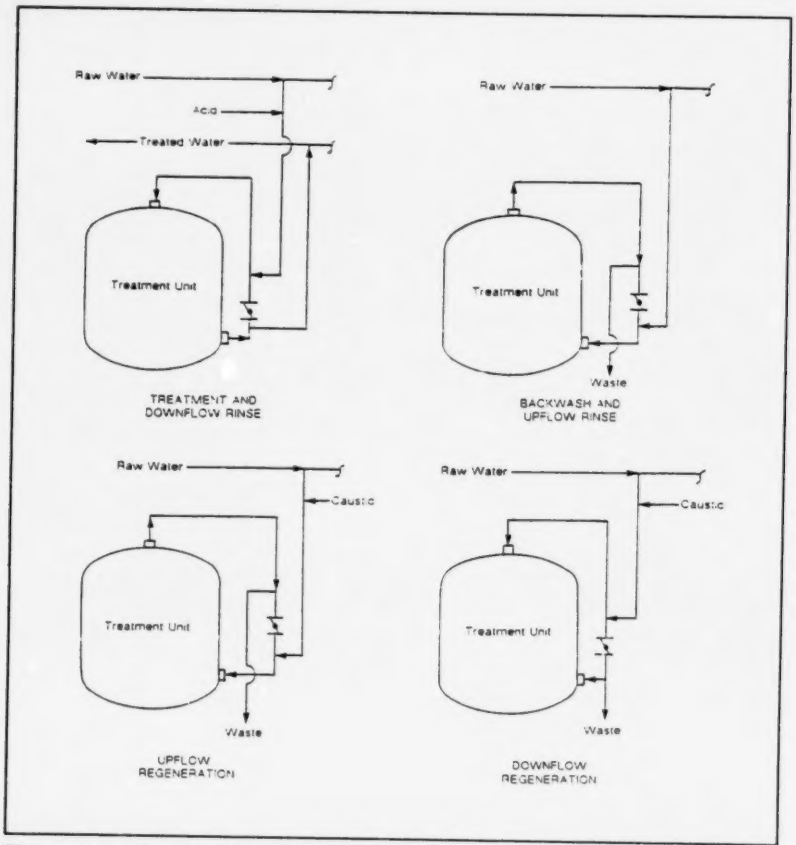

Figure 7-3. Activated alumina systems: Operating mode flow schematics.

alumina is the long contact time required (5 minutes, compared to 2 to 3 minutes for ion exchange). Finally, activated alumina's costs are higher than those for ion exchange. Waste management might also increase costs because of high concentrations of aluminum and other contaminants in the waste stream, as well as high pH.

Technologies for Radon Removal: Aeration and Granular Activated Carbon

Several low-cost/low-technology aeration techniques can effectively lower the concentration of radon in drinking water. (Radon is a naturally occurring radioactive gas that contaminates ground water in some geographical areas.) These techniques include open air storage with no mixing, a flow-through reservoir system with influent control devices, and a flow-through reservoir with bubble aeration. Initial studies found that minimal aeration applied during 30 hours of storage can achieve more than 95 percent radon removal.[14]

Another relatively low-cost aeration technique is a multistaged diffused bubble aeration system manufactured by Lowry Engineering, Inc. of Unity, Maine. This process is applied in a box-shaped, low profile vessel made of high density polyethylene. It is designed to remove volatile organic chemicals as well as radon. Packed tower aeration also is commonly used to remove radon. The size of the packed tower required for radon removal generally is much less than for organics removal.

Granular activated carbon (GAC) can also effectively remove radon from water. There are, however, concerns about worker safety and disposal of carbon that is contaminated with radon.[15]

Aeration and GAC are discussed in greater detail in Chapter 6, Treating Organic Contaminants in Drinking Water.

[14] N.E. Kinner, C.E. Lessard, G.S. Schell, and K.R. Fox. "Low-Cost/Low-Technology Aeration Techniques for Removing Radon from Drinking Water," Environmental Research Brief, U.S. Environmental Protection Agency, Office of Research and Development, September 1987. EPA/600/M-87/031.

[15] N.E. Kinner, C.E. Lessard, and G.S. Schell, *Radon Removal from Small Community Water Supplies Using Granular Activated Carbon and Low Technology/Low Cost Techniques*, U.S. Environmental Protection Agency Cooperative Research Agreement CR-81-2602-01-0.

Chapter Eight

Resources

Safe Drinking Water Hotline

1-800-426-4791
1-202-382-5533

This hotline, run by the U.S. Environmental Protection Agency, provides information on drinking water regulations, policies, and documents to the public, state and local government, public water systems, and consultants. The Safe Drinking Water Hotline's hours are 8:30 a.m. to 4:30 p.m. Eastern Standard Time, Monday through Friday excluding holidays.

U.S. Environmental Protection Agency Regional Offices

Regional offices of the U.S. Environmental Protection Agency are listed in Table 8-1.

State Drinking Water Agencies

State agencies responsible for public water supervision are listed in Table 8-2.

Organizations Assisting Small Systems

American Water Works Association (AWWA) Small Systems Program

This program provides information, training, and technical assistance to small systems, in coordination with state regulatory agencies and other organizations assisting small systems. Contact the AWWA at 6666 W. Quincy Avenue, Denver, CO 80235 (303-794-7711) for the name of a contact for the small systems program in your area.

National Rural Water Association (NRWA)

This organization provides training and technical assistance to small systems. Contact the NRWA office at P.O. Box 1428, Duncan, OK 73534 (405-252-0629) for national information and the name of your local contact.

Rural Community Assistance Program (RCAP)

This program consists of six regional agencies formed to develop the capacity of rural community officials to solve local water problems. It provides onsite technical assistance, training, and publications, and works to improve federal and state government responsiveness to the needs of rural communities. Table 8-3 lists the six RCAP regional agencies.

Farmers Home Administration (FmHA)

The Farmers Home Administration provides grants and loans for rural water systems and communities with populations less than 25,000. Contact FmHA at USDA/FmHA, 14th and Independence Avenue SW, Washington, DC 20250 (202-447-4323).

Publications

General

American Water Works Association. *Basic Management Principles for Small Water Systems.* Denver, Co, 1982.

American Water Works Association. *Design and Construction of Small Water Systems—A Guide for Managers.* 1984.

American Water Works Association. *Introduction to Water Treatment.* Denver, CO, 1984.

Concern, Inc. *Drinking Water: A Community Action Guide.* Washington, DC (1794 Columbia Road, NW, Washington, DC 20009), December 1986.

National Rural Water Association. *Water System Decision Makers: An Introduction to Water System Operation and Maintenance.* Duncan, OK, 1988.

Opflow. A monthly publication of the American Water Works Association focusing on the "nuts and bolts" concerns of treatment plant operators.

Table 8-1. EPA Regional Offices

EPA Headquarters

401 M Street, SW
Washington, DC 20460
202-382-5043

EPA Region 1

JFK Federal Building
Boston, MA 02203
617-565-3424

Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, Vermont

EPA Region 2

26 Federal Plaza
New York, NY 10278
212-264-2515

New Jersey, New York, Puerto Rico, Virgin Islands

EPA Region 3

841 Chestnut Street
Philadelphia, PA 19107
215-597-9370

Delaware, Maryland, Pennsylvania, Virginia, West Virginia, District of Columbia

EPA Region 4

345 Courtland Street, NE
Atlanta, GA 30365
404-347-3004

Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee

EPA Region 5

230 South Dearborn Street
Chicago, IL 60604
312-353-2000

Illinois, Indiana, Ohio, Michigan Minnesota, Wisconsin

EPA Region 6

1445 Ross Avenue
Dallas, TX 75202
214-655-2200

Arkansas, Louisiana, New Mexico, Oklahoma, Texas

EPA Region 7

726 Minnesota Avenue
Kansas City, KS 66101
913-236-2803

Iowa, Kansas, Missouri, Nebraska

EPA Region 8

One Denver Place
999 18th Street, Suite 1300
Denver, CO 80202
303-293-1692

Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming

EPA Region 9

215 Fremont Street
San Francisco, CA 94105
415-974-8083

Arizona, California, Hawaii, Nevada, American Samoa, Guam, Trust Territories of the Pacific

EPA Region 10

1200 Sixth Avenue
Seattle, WA 98101
206-442-1465

Alaska, Idaho, Oregon, Washington

Table 8-2. State Drinking Water Agencies

Region I

Connecticut Department of Health Services
Water Supplies Section
150 Washington Street
Hartford, CT 06106
203-566-1251

Division of Water Supply
Department of Environmental Protection
One Winter Street, 9th Floor
Boston, MA 02108
617-292-5529

Drinking Water Program
Division of Health Engineering
Maine Department of Human Services
State House (STA 10)
Augusta, ME 04333
207-289-3826

Water Supply Engineering Bureau
Department of Environmental Services
P.O. Box 95, Hazen Drive
Concord, NH 03302-0095
603-271-3503

Division of Drinking Water Quality
Rhode Island Department of Health
75 Davis Street, Cannon Building
Providence, RI 02908
401-277-6867

Water Supply Program
Vermont Department of Health
60 Main Street
P.O. Box 70
Burlington, VT 05402
802-863-7220

Region II

Bureau of Safe Drinking Water
Division of Water Resources
New Jersey Department of
Environmental Protection
P.O. Box CN-029
Trenton, NJ 06825
609-984-7945

Bureau of Public Water Supply Protection
New York State Department of Health
2 University Place
Western Avenue, Room 406
Albany, NY 12203-3313
518-458-6731

Water Supply Supervision Program
Puerto Rico Department of Health
P.O. Box 70184
San Juan, PR 00936
809-766-1616

Planning and Natural Resources
Government of Virgin Islands
Nifky Center, Suite 231
St. Thomas, Virgin Islands 00802

Region III

Office of Sanitary Engineering
Delaware Division of Public Health
Cooper Building
P. O. Box 637
Dover, DE 19903
302-736-4731

Water Supply Program
Maryland Department of the Environment
Point Breeze Building 40, Room 8L
2500 Broening Highway
Dundalk, MD 27224
301-631-3702

Water Hygiene Branch
Department of Consumer and Regulatory Affairs
5010 Overlook Avenue, SW
Washington, DC 20032
202-767-7370

Division of Water Supplies
Pennsylvania Department of Environmental
Resources
P.O. Box 2357
Harrisburg, PA 17105-2357
717-787-9035

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Table 8-2. State Drinking Water Agencies (continued)

Evironmental Engineering Division
Office of Environmental Health Services
State Department of Health
Capital Complex Building 3, Room 550
1900 Kanawha Blvd., East
Charleston, WV 25305
304-348-2981

Division of Water Supply Engineering
Virginia Department of Health
James Madison Building
109 Governor Street
Richmond, VA 23219
804-786-1766

Region IV

Water Supply Branch
Department of Environmental Management
1751 Congressional W.L. Dickinson Drive
Montgomery, AL 36130
205-271-7773

Drinking Water Section
Department of Environmental Regulation
Twin Towers Office Building
2600 Blair Stone Road
Tallahassee, FL 32399-2400
904-487-1779

Drinking Water Program
Georgia Environmental Protection Division
Floyd Towers East, Room 1066
205 Butler Street, S.E.
Atlanta, GA 30334
404-656-5660

Drinking Water Branch
Division of Water
Department of Environmental Protection
18 Reilly Road, Frankfort Office Park
Frankfort, KY 40601
502-564-3410

Division of Water Supply
State Board of Health
P.O. Box 1700
Jackson, MS 39215-1700
601-354-6616/490-4211

Public Water Supply Section
Division of Environmental Health
Department of Environment, Health and
Natural Resources
P.O. Box 27687
Raleigh, NC 27611-7687
919-733-2321

Bureau of Drinking Water Protect
Department of Health and
Environmental Control
2600 Bull Street
Columbia, SC 29201
803-734-5310

Division of Water Supply
Tennessee Department of Health
and Environment
150 Ninth Avenue, North
Terra Building, 1st Floor
Nashville, TN 37219-5404
615-741-6636

Region V

Division of Public Water Supplies
Illinois Environmental Protection Agency
2200 Churchill Road
P.O. Box 19276
Springfield, IL 62794-9276
217-785-8653

Public Water Supply Section
Office of Water Management
Indiana Department of Environmental Manage-
ment
105 South Meridian
P.O. Box 6015
Indianapolis, IN 46206
317-633-0174

Division of Water Supply
Michigan Department of Public Health
P.O. Box 30195
Lansing, MI 48909
517-335-8318

Minnesota Department of Health
Section of Water Supply and Well Management
Division of Environmental Health
925 S.E. Delaware Street
P.O. Box 59040
Minneapolis, MN 55459-0040
612-627-5170

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Table 8-2. State Drinking Water Agencies (continued)

Division of Public Drinking Water
Ohio Environmental Protection Agency
1800 WaterMark Drive
P.O. Box 1049
Columbus, OH 43266-0149
614-644-2752

Bureau of Water Supply
Department of Natural Resources
P.O. Box 7921
Madison, WI 53707
608-267-7651

Region VI

Division of Engineering
Arkansas Department of Health
4815 West Markham Street - Mail Slot 37
Little Rock, AR 72205-3867
501-661-2000

Office of Public Health
Louisiana Department of Health and Hospitals
P.O. Box 60630
New Orleans, LA 70160
504-568-5105

Drinking Water Section
New Mexico Health and Environment Department
1190 St. Francis Drive
Room South 2058
Santa Fe, NM 87503
505-827-2778

Water Quality Service
Oklahoma State Department of Health
P.O. Box 53551
Oklahoma City, OK 73152
405-271-5204

Bureau of Environmental Health
Texas Department of Health
1100 W. 49th Street
Austin, TX 78756-3199
512-458-7533

Region VII

Surface and Groundwater Protection Bureau
Environmental Protection Division
Iowa Department of Natural Resources
Wallace State Office Building
900 East Grand Street
Des Moines, IA 50319
515-281-8998

Public Water Supply Section
Bureau of Water
Kansas Department of Health and Environment
Forbes Field, Building 740
Topeka, KS 66620
913-296-1500

Public Drinking Water Program
Division of Environmental Quality
Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, MO 65102
314-751-5331

Division of Drinking Water and Environmental Sanitation
Nebraska Department of Health
301 Sentenial Mall South
P.O. Box 95007, 3rd Floor
Lincoln, NE 68509
402-471-2541

Region VIII

Drinking Water Program
Colorado Department of Health
4210 East 11th Avenue
Denver, CO 80220
303-320-8333

Water Quality Bureau
Department of Health and Environmental Sciences
Cogswell Building, Room A206
Helena, MT 59620
406-444-2406

Division of Water Supply and Pollution Control
ND State Department of Health and Consolidated Laboratories
1200 Missouri Avenue
P. O. Box 5520
Bismark, ND 58502-5520
702-224-2370

Office of Drinking Water
Department of Water and Natural Resources
Joe Foss Building
523 East Capital Avenue
Pierre, SD 57501
605-773-3151

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Table 8-2. State Drinking Water Agencies (continued)

Bureau of Drinking Water/Sanitation
Utah Department of Health
P.O. Box 16690
Salt Lake City, UT 84116-0690
801-538-6159

DEQ - Water Quality
Herschler Building, 4 West
122 West 25th Street
Cheyenne, WY 82002
307-777-7781

Region IX

Field Services Section
Office of Water Quality
2655 East Magnolia Street
Phoenix, AR 85034
602-257-2305

Office of Drinking Water
California Department of Health Services
714 P Street, Room 692
Sacramento, CA 95814
916-323-6111

Safe Drinking Water Branch
Environmental Management Division
P.O. Box 3378
Honolulu, HI 96801-9984
808-548-4682

Public Health Engineering
Nevada Department of Human Resources
Consumer Health Protection Services
505 East King Street, Room 103
Carson City, NV 89710
702-885-4750

Guam Environmental Protection Agency
Government of Guam
Harmon Plaza Complex Unit D-107
130 Rojas Street
Harmon, Guam 96911

Division of Environmental Quality
Commonwealth of the Northern Mariana Islands
P.O. Box 1304
Saipan, CM 96950
670-322-9355

Marshall Islands Environmental Protection
Authority
P.O. Box 1322
Majuro, Marshall Islands 96960
Via Honolulu

Government of the Federated States of Micronesia
Department of Human Resources
Kolonia, Pohnpei 96941

Palau Environmental Quality Protection Board
Hospital
Koror, Palau 96940

Region X

Alaska Drinking Water Program
Wastewater and Water Treatment Section
Department of Environmental Conservation
P.O. Box O
Juneau, AK 99811-1800
907-465-2653

Bureau of Water Quality
Division of Environmental Quality
Idaho Department of Health
and Welfare
Statehouse Mail
Boise, ID 83720
208-334-5867

Drinking Water Program
Department of Human Resources
Health Division
1400 S.W. 5th Avenue, Room 608
Portland, OR 97201
503-229-6310

Drinking Water Section
Department of Health
Mail Stop LD-11, Building 3
Airdustrial Park
Olympia, WA 98504
206-753-5954

Table 8-3. Rural Community Assistance Program (RCAP) Agencies

Community Resources Group, Inc.
2705 Chapman
Springdale, AR 72764
501-756-2900

Great Lakes Rural Network
109 South Front Street
Freemont, OH 43420
419-334-8911

Midwest Assistance Program, Inc.
P.O. Box 81
New Prague, MN 56071
612-758-4334

Rural Community Assistance Corporation
2125 19th Street, Suite 203
Sacramento, CA 95818
916-447-2854

Rural Housing Improvement, Inc.
218 Central Street, Box 429
Winchendon, MA 01475-0429
617-297-1376

Virginia Water Project, Inc.
Southeastern Rural Community
Assistance Program
702 Shenandoah Avenue, NW
P.O. Box 2868
Roanoke, VA 24001
703-345-6781

Publications *(continued)*

Schautz, Jane W. *The Self-Help Handbook.* This manual gives specific guidelines and techniques for establishing self-help projects (projects where the community does some of the work itself to save money). Focus is on improving or creating water and wastewater systems in small rural communities. For ordering information, contact: Rensselaerville Institute, Rensselaerville, NY 12147 (518-797-3783).

U.S. Environmental Protection Agency, Office of Drinking Water. *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.* EPA 570/9-89-018. October 1989.

U.S. Environmental Protection Agency, Office of Drinking Water. *Manual of Individual Water Supply Systems.* EPA 570/9-82-004. October 1982.

Sampling

U.S. Environmental Protection Agency, Office of Research and Development. *Handbook for Sampling and Sample Preservation of Water and Wastewater.* EPA 600/4-82-029. September 1982.

Filtration

American Water Works Association Research Foundation. *Manual of Design for Slow Sand Filtration.* (To be published Fall 1990.)

Huisman, L. and Wood, W.E. *Slow Sand Filtration.* World Health Organization, Geneva. 1974.

Slezak, L.A. and Sims, R.C. "The Application and Effectiveness of Slow Sand Filtration in the United States." *Journal AWWA,* 76:1238-43. 1984.

Visscher, J.T., Paramasivam, R., Raman, A., and Heijnen, H.A. *Slow Sand Filtration for Community Water Supply.* Technical Paper 24. International Reference Centre for Community Water Supply and Sanitation, The Hague, The Netherlands. 1987.

Disinfection

American Water Works Association. *Water Chlorination Principles and Practices* (M20). 1973.

SMC Martin, Inc. *Microorganism Removal for Small Water Systems.* EPA 570/9-83-012. Valley Forge, PA. June 1983.

Corrosion Control

U.S. Environmental Protection Agency, Office of Drinking Water. *Corrosion Manual for Internal Corrosion of Water Distribution Systems.* EPA 570/9-84-001. April 1984.

Economic and Engineering Services. *Lead Control Strategies.* American Water Works Association Research Foundation. Denver, CO. 1989.

Radionuclide Removal

Kinner, N.E., Lessar, C.E., Schell, G.S., and Fox, K.R., "Low Cost/Low-Technology Aeration Techniques for Removing Radon from Drinking Water." EPA/600/M-87-031. U.S. Environmental Protection Agency, Office of Research and Development. September 1987.

SMC Martin, Inc. *Radionuclide Removal for Small Public Water Systems.* EPA 570/9-83-010. Valley Forge, PA. June 1983.

Wellhead Protection

U.S. Environmental Protection Agency, Office of Ground-Water Protection. *Wellhead Protection: A Decision Maker's Guide.* 1987.

U.S. Environmental Protection Agency, Office of Ground-Water Protection. *Developing a State Wellhead Protection Program: A User's Guide to Assist State Agencies Under the Safe Drinking Water Act.* 1988.

U.S. Environmental Protection Agency, Office of Ground-Water Protection. Ground-Water Protection Document Request Form.

Costs/Financial Management

American Water Works Association. *Water Utility Capital Financing* (M 29). 1988.

Gumerman, R.C., Burris, B.E., and Hansen, S.P. *Estimation of Small System Water Treatment Costs.* Final Report. Culp/Wesner/Culp. Municipal Environmental Research Lab, Cincinnati, OH, 1984.

U.S. Environmental Protection Agency, Office of Water. *A Water and Wastewater Manager's Guide for Staying Financially Healthy.* EPA 430/09-89-004. July 1989.

U.S. Environmental Protection Agency, Office of Ground-Water Protection. *Local Financing for Wellhead Protection.* 1989.

Consultants

Directory—Professional Engineers in Private Practice. Published by the National Society of Professional Engineers. Contact SPE Order Department, 1420 King Street, Alexandria, VA 22314.

Who's Who in Environmental Engineering. Published by the American Academy of Environmental Engineers. Contact the American Academy of Environmental Engineers, 132 Holiday Court, Suite 206, Annapolis, MD 21401.

The Federal Register

The *Federal Register* is published daily to make available to the public regulations and legal notices issued by federal agencies. It is distributed by the U.S. Government Printing Office, Washington, DC 20402. To order copies, call 1-202-783-3238.

A wide variety of publications on specific topics of concern to water systems is available from the American Water Works Association and the National Rural Water Association.

Appendix A

How to Take Bacteriological Samples

Routine and special bacteriological samples must be taken in accordance with established procedures to prevent accidental contamination, and analyzed by an EPA- or state-certified laboratory. The laboratory will usually provide specially prepared sampling containers, properly sterilized and containing sodium thiosulfate to destroy any remaining chlorine. The following steps should be followed in coliform sampling:

1. Use only containers that are provided by the bacteriological laboratory and that have been prepared for coliform sampling. Follow all instructions for sample container handling and storage.

   The containers are sterile. Do not open them before use and do not rinse them.

2. Take samples at the consumer's faucet, but avoid:
   - Faucets with aerators (unless removed) or swivel spouts
   - Taps inside homes served by home water treatment units such as water softeners
   - Locations where the water enters separate storage tanks
   - Leaking faucets that permit water to run over the outside of the faucet

3. Always allow the water to flow moderately from a faucet 2 or 3 minutes before taking the sample.

4. Hold the sample container at the base, keeping hands away from the container neck. Be sure the inside of the container cap is protected and does not touch anything.

5. Without adjusting the flow, fill the sample container, leaving about 20 percent air space at the top. Replace the cap immediately. If the sample is taken incorrectly, take another sample container —do not reuse the original bottle.

6. Take a second sample and measure the concentration of the disinfectant and record relevant information (date, time, concentration, place, sampler, etc.).

7. Package the bacteriological sample for delivery to the laboratory. Record all pertinent field information on a form and on the sample container label.

8. Samples must be cool during shipment to the laboratory. Use insulated boxes for shipping containers if needed, or refrigerate during transit.

Do not allow more than 30 hours between sampling and test times.

Be sure the laboratory can process the samples immediately upon receipt.

Source: SMC Martin, Inc., *Microorganism Removal for Small Water Systems*, June 1983. EPA 570/9-83-010.

Appendix B

Checklist: Some Factors Affecting Water Treatment System Performance

Administration

1. Does the manager have first-hand knowledge of plant needs through plant visits and discussions with operators?
2. Are there long-range plans for facility replacement, alternative source waters, emergency response, etc.?
3. Is there an adequate number of personnel to accomplish necessary operational activities?
4. Are staff adequately trained and able to make proper operation and maintenance decisions?
5. Are adequate funds available for spare parts, improvements or replacement of equipment, required chemicals, etc.?
6. Are the plant unit processes adequate to meet the demand for finished water?
7. Is the staff aware of the potential sources of contamination that might affect the drinking water supply and the available management methods?

Maintenance

1. Is there an effective scheduling and recording procedure to prevent equipment failures, excessive downtime, etc. resulting in plant performance or reliability problems?
2. Is the spare parts inventory adequate to prevent long delays in equipment repairs?
3. Are procedures available to initiate maintenance activities on equipment operating irregularities? Are emergency response procedures in place to protect process needs if critical equipment breaks down?
4. Are good housekeeping procedures followed?
5. Are equipment reference sources available (such as operation and maintenance manuals, equipment catalogs, etc.)?
6. Does the plant staff have necessary expertise to keep equipment operating and to make equipment repairs when necessary?
7. Are technical resources (such as equipment suppliers or contract service) available to provide guidance for repairing, maintaining, or installing equipment?
8. Are old or outdated pieces of equipment replaced as necessary to prevent excessive equipment downtime or inefficient process performance/reliability?

Design

1. Is the plant design adequate for raw water quality (e.g., turbidity, temperature, seasonal variation, etc.)?
2. Do facilities exist to control raw water quality entering the plant (e.g., can intake levels be varied, can chemicals be added to control aquatic growth, do watershed management practices adequately protect raw water quality)?
3. Are the size of filters and type, depth, and effective size of filtration media adequate? Are the surface wash and backwash facilities adequate to maintain a clear filter bed?
4. Are design features of the disinfection system adequate (proper mixing, detention time, feed rates, proportional feed, etc.)?
5. Are sludge facilities and size of the sludge disposal area adequate?
6. Do process control features provide adequate measurement of plant flow rate, backwash flow rate, filtration rate, and flocculation mixing in-

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puts? Do chemical feed facilities provide adjustable feed ranges that are easily set for operation at all required dosages? Are chemical feed rates easily measured?

7. Are automatic monitoring or control devices used where needed to avoid excessive operator time for process control and monitoring?

8. Are standby units for key equipment available to maintain process performance during breakdown or during preventive maintenance activities?

Operation

1. Are plant and distribution monitoring tests representative of performance?

2. Is the proper process control testing performed to support operational control decisions?

3. Does the plant staff have sufficient understanding of water treatment process control testing and plant needs to make proper process control adjustments?

4. Has the plant staff received appropriate operational information from technical resources (e.g., design engineer, equipment representative, state trainer or inspector) to enable them to make proper operational decisions?

5. Does the operation and maintenance manual/procedure provide appropriate guidance for operational decisions? Do operators utilize the manual?

6. Are distribution system operating procedures adequate to protect the integrity of finished water (e.g., flushing, reservoir management)?

Source: Adapted from U.S. Environmental Protection Agency, Office of Research and Development and Center for Environmental Research Information, *Summary Report: Optimizing Water Treatment Plant Performance with the Composite Correction Program*, March 1990. EPA 625/8-90/017.

Appendix C

Selecting a Consulting Engineer

Selecting the right consultant involves the following steps:

1. **Identifying potential engineering firms.** Start by drawing up a list of at least five firms that might be able to meet your needs. Sources of names include your own past experience or that of neighboring towns, lists maintained by your state drinking water agency, and suggestions received from the local Rural Community Assistance Program. Local professional engineering societies may be able to provide lists of members who specialize in drinking water treatment work. The National Society of Professional Engineers and the American Academy of Environmental Engineers have lists of their members available (see Chapter 8, Resources).

2. **Issuing a Request for Proposals.** Notify engineering firms that you are interested in their services. One good way to do this is by preparing a Request for Proposals (RFP). In your RFP, briefly describe your town's water treatment problem and request proposals from consultants on how they would solve it.

   Depending on your community's size and the nature of your problem, the RFP may be a letter to the engineering firms on your list or it may be a longer, more formal document. You may wish to advertise your RFP. In any case, it should include at least the following:

   - A brief description of the problem
   - A statement telling what it is you want the consulting firm to do
   - The deadline by which your town must receive the proposal
   - The person in your town to contact for additional information
   - Standards by which the proposals will be judged
   - The place and time the proposal must be submitted

3. **Interviewing candidate engineering firms.** When you receive the proposals, check to see if they meet your judging standards, and are within an acceptable cost range. From those that meet the standards, select three or four and interview each firm individually.

   The following criteria may be helpful in evaluating engineering firms:

   - **Small town experience.** Does the firm have experience with communities like yours? Which towns have they worked with in the recent past?
   - **System design experience.** Does the firm have experience in designing systems for small communities? What types of systems has the firm actually recommended, designed, and installed? When were they installed? How are these systems working? What were the estimated costs? What are the present operation and maintenance needs and costs of these systems? What systems has the firm recommended for communities that are most like your own? Ask for the cost per dwelling serviced, the up-front assessments, and monthly charges for the last few projects of a size and technology comparable to your situation.

Sources: Adapted from U.S. Environmental Protection Agency, Office of Municipal Pollution Control, *It's Your Choice: A Guidebook for Local Officials on Small Community Wastewater Management Options*, September 1987. EPA 430/9-87-006; SMC Martin, Inc., *Microorganism Removal for Small Water Systems*, June 1983. EPA 570/9-83-012.

- **Experience with financial institutions and funding agencies**. What experience has the firm had in helping communities get financing from commercial sources (banks, bond sales)? What experience has the firm had in dealing with state grant or loan programs or Farmers Home Administration grant and loan programs? What experience has the firm had in working with lending institutions or financial consultants?

- **Experience with state and county agencies**. What experience does the firm have in working with the state and county environmental agencies, the health department, etc.?

- **Willingness to work with the community**. If your community came up with a range of acceptable user costs, would the engineer be willing to use these estimates as guidelines to design a drinking water treatment system? How does the firm plan to handle public participation in this project?

- **Willingness to work for the community.** Does the firm have any experience in using technologies and maintenance programs that are different from what the state and county agencies have traditionally accepted? Does the firm have the willingness and capability to utilize innovative or alternative technology where appropriate? (Some engineers have dealt only with large centralized treatment systems and might not be familiar or experienced with other alternatives.)

- **Staff capabilities and workload.** What projects is the firm now working on and what new ones may be coming soon? Which people on their staff will be devoted to your project? What time schedule does the firm propose for completing your work? Does the firm use subcontractors for certain work? If so, which firms and for what work?

- **Cost of engineering work**. Be prepared to pay for good engineering work. Do not choose your engineer only on the basis of cost. It is well worth spending a little extra to get an engineer who will design a system that will provide service at lower cost for years to come. Ask the engineer to briefly explain the firm's estimated fee. Make sure you understand exactly what services will be provided. Is there a distinction between basic services and additional services? What circumstances could significantly change the estimate?

4. **Checking references.** Be sure to check references for the firms you thought were best. Talk to representatives from communities the firm has recently worked for. Ask about the overall experience, problems or special situations that arose, delays, etc.

5. **Selecting a firm and contracting for its services.** The final selection of a firm involves evaluating all the information you have gathered. Once you have selected a firm, you must negotiate and sign a contract for their services. The form of this contract and the payment may be governed by the method your town will use to finance this part of your project. Be sure to consider this aspect in your evaluation. When that is done, you are ready to begin working with the engineer to evaluate and solve your town's drinking water treatment problems.

The consultant should do the following to achieve the best system design and to simplify the operator's job:

- Establish a high level of communication with the community and representatives of the drinking water treatment facility, and become familiar with the unique features and requirements of the utility, as well as the responsiveness of regional chemical suppliers and equipment vendors.

- Conduct sufficient laboratory and pilot plant studies and observations of the source waters to fully characterize them. New facilities should be adequate to handle the full range of expected water conditions, including foreseeable water quality deterioration.

- Initiate the design process with a thorough review of all possible non-treatment or minimal treatment approaches. Consider potential ease of maintenance, adequate space and light, and simplicity in the design and equipment. Avoid overly elaborate control systems, and include appropriate redundance (i.e., never only one chlorinator).

- Avoid dead ends in the distribution system. Provide equipment for flushing and sampling, for storage, and for emergency chlorination of the distribution system.

- Allow operating personnel to participate in design decisions and observe construction progress.

- Prepare operation and maintenance manuals, which include the following information:

  - the original design concepts
  - description and drawings of the facility as constructed
  - normal operational procedures
  - emergency operational procedures
  - organized collection of vendors' literature
  - safety considerations and requirements

- schematics with all valves numbered to correspond to detailed operational procedures
- maintenance procedures

- Provide startup assistance and training and followup engineering services.

Appendix D

Chlorine Residual Monitoring

Chlorine in its most active form—as "free residual chlorine"—is stable only in the absence of agitation, sunlight, and certain organic and inorganic materials with which it can react.

Reactions of free residual chlorine with chlorine demanding substances continue over long periods of time. Therefore, the sample taken for disinfectant analysis should be analyzed immediately. Specially prepared sampling containers, properly cleansed, sterilized, and not containing sodium thiosulfate should be used.

In general, the same sampling precautions described in Appendix A for taking coliform samples should be observed, but in addition:

1. Draw the sample gently, avoiding agitation.

2. Analyze immediately in the shade or subdued light. Do not store the sample.

3. Do not use a bacteriological sampling container, which may contain a chemical to counteract or destroy the disinfecting agent.[a]

Demonstration of Maintaining a Residual[b]

The Surface Water Treatment Rule (SWTR) establishes two requirements pertaining to the maintenance of a residual. The first requirement is to maintain a minimum residual of 0.2 mg/L entering the distribution system. Also, a detectable residual must be maintained throughout the distribution system. These requirements are further explained in the following sections.

Maintaining a Residual Entering the System

The SWTR requires that a residual of 0.2 mg/L be maintained in the water entering the distribution system at all times. Continuous monitoring at the entry point(s) to the distribution system is required to ensure that a detectable residual is maintained. Any time the residual drops below 0.2 mg/L, the system must notify the Primacy Agency[c] prior to the end of the next business day. The system is in violation of a treatment technique if the residual level is not restored to 0.2 mg/L within 4 hours and filtration must be installed. (If the Primacy Agency finds that the exceedence was caused by an unusual and unpredictable circumstance, it may choose not to require filtration.) In cases where the continuous monitoring equipment fails, grab samples every 4 hours may be used for a period of 5 working days while the equipment is restored to operable conditions.

The system must record, each day of the month, the lowest disinfectant residual entering the system and this residual must not be less than 0.2 mg/L. Systems serving less than or equal to 3,300 people may take grab samples in lieu of continuous monitoring at the frequencies shown in the box below:

System Population	Samples/day*
<500	1
501-1,000	2
1,001-2,500	3
>2,501-3,000	4

*Samples must be taken at dispersed time intervals as approved by the Primacy Agency.

[a] From SMC Martin, Inc., *Microbiological Removal for Small Water Systems*, June 1983. EPA 570/9-83-010.

[b] Adapted from U.S. Environmental Protection Agency, *Guidance for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources*, October 1989.

[c] The Primary Agency is a state with primary enforcement responsibility for public water supplies, or EPA in the case of a state that has not obtained primacy.

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If the residual concentration falls below 0.2 mg/L, another sample must be taken within 4 hours and sampling continued at least every 4 hours until the disinfectant residual is a minimum of 0.2 mg/L.

Maintaining a Residual within the System

The SWTR also requires that a detectable disinfectant residual be maintained throughout the distribution system, with measurements taken at a minimum frequency equal to that required by the Total Coliform Rule (54 FR 27543-27568). The same sampling locations as required for the coliform regulation must be used for taking the disinfectant residual or HPC (heterotrophic plate count) samples. However, for systems with both groundwater and surface water sources (or ground water under the direct influence of surface water) entering the distribution system, residuals may be measured at points other than coliform sampling points if these points are more representative of the disinfected surface water and allowed by the Primacy Agency. An HPC level of less than 500/mL is considered equivalent to a detectable residual for the purpose of determining compliance with this requirement, since the absence of a disinfectant residual does not necessarily indicate microbiological contamination.

Disinfectant residual can be measured as total chlorine, free chlorine, combined chlorine, or chlorine dioxide (or HPC level). The SWTR lists the approved analytical methods for these analyses. For example, several test methods can be used to test for chlorine residual in the water, including amperometric titration, DPD colorimetric method, DPD ferrous titrimetric method, and iodometric method, as described in the 16th Edition of *Standard Methods for the Examination of Water and Wastewater*, APHA, AWWA, and WPCF, Washington, DC, 1985.[d]

The SWTR requires that a detectable disinfectant residual be present in 95 percent or more of the monthly distribution system samples. In systems that do not filter, a violation of this requirement for 2 consecutive months caused by a deficiency in treating the source water will trigger a requirement for filtration to be installed. Therefore, a system that does not maintain a residual in 95 percent of the samples for 1 month because of treatment deficiencies, but is maintaining a residual in 95 percent of the samples for the following month, will meet this requirement.

The absence of a detectable disinfectant residual in the distribution system may be due to a number of factors, including:

- Insufficient chlorine applied at the treatment plant
- Interruption of chlorination
- A change in chlorine demand in either the source water or the distribution system
- Long standing times and/or long transmission distances

Available options for systems to correct the problem of low disinfectant residuals within their distribution system include:

- Routine flushing
- Increasing disinfectant doses at the plant
- Cleaning of the pipes (either mechanically by pigging or by the addition of chemicals to dissolve the deposits) in the distribution system to remove accumulated debris that may be exerting a disinfectant demand
- Flushing and disinfection of the portions of the distribution system in which a residual is not maintained
- Installation of satellite disinfection feed facilities with booster chlorinators within the distribution system

For systems unable to maintain a residual, the Primacy Agency may determine that it is not feasible for the system to monitor HPCs and judge that disinfection is adequate based on site-specific conditions.

Additional information on maintaining a residual in the system is available in the American Water Works Association's *Manual of Water Supply Practices and Water Chlorination Principles and Practices.*

[d] Also, portable test kits are available that can be used in the field to detect residual upon approval of the Primacy Agency. These kits may employ titration or colorimetric test methods. The colorimetric kits employ either a visual detection of a residual through the use of a color wheel, or the detection of the residual through the use of a hand held spectrophotometer.

Appendix E

CT Values

CT Values for Achieving Inactivation of Viruses at pH 6 through 9 (in mg L-m)

	Log Inacti-vaton	Temperature					
		0.5°C	5°C	10°C	15°C	20°C	25°C
Free chlorine[a]	2	6	4	3	2	1	1
	3	9	6	4	3	2	1
	4	12	8	6	4	3	2
Ozone	2	0.9	0.6	0.5	0.3	0.25	0.15
	3	1.4	0.9	0.8	0.5	0.4	0.25
	4	1.8	1.2	1.0	0.6	0.5	0.3

[a]CT values include a safety factor of 3.

CT Values for Achieving 99.9 Percent Inactivation of *Giardia Lamblia*[1]

		Temperature					
Disinfectant	pH	0.5°C	5°C	10°C	15°C	20°C	25°C
Free chlorine[b]	6	165	116	87	58	44	29
	7	236	165	124	83	62	41
	8	346	243	182	122	91	61
	9	500	353	265	177	132	88
Ozone	6-9	2.9	1.9	1.4	0.95	0.72	0.48

[a]These CT values for free chlorine, chlorine dioxide, and ozone will guarantee greater than 99.99 percent inactivation of enteric viruses.

[b] CT values will vary depending on concentration of free chlorine. Values indicated are for 2.0 mg/L of free chlorine. CT values for different free chlorine concentrations are specified in tables in the EPA *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.*

CT Values for Achieving 90 Percent Inactivation of *Giardia Lamblia* (in mg/L-m)

Disinfectant	pH	Temperature 0.5°C	5°C	10°C	15°C	20°C	25°C
Free chlorine[a] (2 mg/L)	6	55	39	29	19	15	10
	7	79	55	41	28	21	14
	8	115	81	61	41	30	20
	9	167	118	88	59	44	29
Ozone	6-9	0.97	0.63	0.48	0.32	0.24	0.16

[a]CT values will vary depending on concentration of free chlorine. Values indicated are for 2.0 mg/L of free chlorine. CT values for different free chlorine concentrations are specified in tables in the EPA *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.*

Appendix F

Sample CT Calculation for Achieving 1-log *Giardia*, 2-log Virus Inactivation with Chlorine Disinfection

A 50,000 GPD slow sand filtration plant supplies a community of 500 people with drinking water from a reservoir in a protected watershed. The raw water supply has the following characteristics:

- Turbidity: 5 to 10 NTU
- Total estimated *Giardia* cyst level: less than 1 per 100 mL
- pH: 6.5 to 7.5
- Temperature: 5° to 15°C

An overall removal/inactivation of 3 logs for *Giardia* and 4 logs for viruses is sufficient for this system. The Primacy Agency credits the slow sand filter, which produces water with turbidity ranging from 0.6 to 0.8 NTU, with a 2-log *Giardia* and virus removal. Disinfection must achieve an additional 1-log *Giardia* and 2-log virus removal/inactivation to meet overall treatment objectives.

To begin the calculations for determining the adequacy of the inactivations achieved by the disinfection system, the total contact time must be determined.

In this plant, chlorine for disinfection is added prior to the clearwell, which has a 2,000-gallon capacity. The distance from the plant to the first customer is bridged by a 1,000-foot 2-inch transmission main. The contact time provided in both the clearwell basin and the distribution pipe up to the first customer comprises the total contact time for disinfection.

In the calculations, contact time is represented by T_{10} —the time needed for 10 percent of the water to pass through the basin. In other words, T_{10} describes the time, in minutes, that 90 percent of the water remains in the basin. (For the distribution pipe, contact time is 100 percent of the time that water remains in the pipe.)

The contact time multiplied by the concentration (mg/L) of residual chlorine in the water is the calculated CT value for the system. Proven inactivation of *Giardia* and viruses are correlated to calculated CT values in EPA's *Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources.* (Appendix E contains excerpts from the CT tables in the manual.)

The T_{10} for the clearwell basin can be determined by tracer studies. (Tracer study procedures are described in EPA's *Guidance Manual.*)

On the day represented in this example, the tracer study showed that the T_{10} for the clearwell was 40 minutes at the peak hourly flow rate. At this flow rate, water travels through the transmission main at 211 feet per minute. The distance between the plant and the first customer is 1,000 feet. Thus, the T_{10} for the distribution main is 4.7 minutes (1,000 feet divided by 211 feet per minute).

Other data required for the calculation are:

- Measured chlorine residual: 2.0 mg/L for the clearwell basin and 1.2 mg/L for the distribution main
- Water temperature: 5°C
- Water pH: 7.5

CT values required to achieve various levels of inactivation of *Giardia* and viruses depending on the water temperature, pH, and chlorine residual are provided in the *Guidance Manual.* The calculated CT values (CT_{calc}) based on actual system data are compared to the CT values in the *Guidance Manual* ($CT_{99.9}$ in the case of a 1-log inactivation) to determine whether the inactivations achieved are adequate.

Since, with free chlorine, a 1-log *Giardia* inactivation provides greater than a 4-log virus inactivation, inactivation of *Giardia* is the controlling factor for determining overall reductions.

The calculation of CT and comparison to CT values for 1-log inactivation of *Giardia* provided in the EPA *Guidance Manual* is shown in the box below.

For the basin:

CT_{calc} = Chlorine residual x contact time or
= 2.0 mg/L x 40 minutes = 80 mg/L-min

From the EPA *Guidance Manual*, $CT_{99.9}$ (3-log inactivation) is 200 mg/L-min at 5°C, 2 mg/L chlorine residual, and 7.5 pH.

$$CT_{calc}/CT_{99.9} = \frac{80 \text{ mg/L-min}}{200 \text{ mg/L-min}} = 0.4$$

For the distribution system:

CT_{calc} = 1.2 mg/L x 4.7 minutes = 5.64 mg/L-min

From the EPA *Guidance Manual*, $CT_{99.9}$ is 183 mg/L-min at 5°C, 1.2 mg/L chlorine residual, and 7.5 pH.

$$CT_{calc}/CT_{99.9} = \frac{5.64 \text{ mg/L-min}}{183 \text{ mg/L-min}} = 0.03$$

Summing $CT_{calc}/CT_{99.9}$ for both the basin and the main results in 0.43. This is equivalent to a 1.29-log *Giardia* inactivation determined by:

$$3 \times CT_{calc}/CT_{99.9}$$
$$= 3 \times 0.43 = 1.29 \text{ log}$$

(This calculation is based on a 3-log inactivation; therefore, the ratio is multiplied by 3.)

Thus, the 1.29-log inactivation achieved by disinfection in this system exceeds the 1-log additional inactivation required to meet overall treatment objectives.

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